NORTH NEW ZEALAND

A NATURAL HISTORY OF THE UPPER NORTH ISLAND

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PETER HADDEN

This book is dedicated to my wife, Andrea, and my children, with whom I have enjoyed exploring the natural history of the upper North Island.

top left **Lunchtime in the field with Lucy and Hannah Hadden. Ahipara Plateau, Far North District.**

bottom left **The author exploring caves in the Waitomo District.**

top right **Hunting for more photo opportunities with William and James Hadden. Bream Head, Whangarei District.**

bottom right **William, George and James Hadden navigate the coastline. Moturekareka Island, Auckland.**

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INTRODUCTION

I began writing this book, which in truth is not an original work but more a compilation of the work of many different professionals which I have attempted to put into one tome, to learn more about the natural history of northern New Zealand both for myself and for my five children, William, Lucy, Hannah, James and George, with whom I have explored many of the different nooks and crannies this land has to offer. While writing, editing and reading helpful criticism of the text I have discovered how little I really knew about this subject, and it is my hope that it will provide an introduction into natural history for you, the reader, in the same way it has for me.

There is a gap, I feel, between books written for public consumption and scientific writing, in journals for instance, that needs to be bridged so that the science becomes available to a wider audience. I have written the book with this in mind, in the hope that if another amateur, having read this book, picks up a journal article on the various terranes of New Zealand or the vegetation zones on Mt Pureora, they can have a decent stab at trying to understand it. I also hope that there is enough general science in it that, having read this book, if you were to pick up a book on the natural history of California or visit the Highlands of Scotland, you could make sense of what you read because of the shared general principles. I believe that the more one understands one's own environment, the better one can understand others, and that applies to more than just natural history.

This book started as a collection of interesting excerpts, but after seeing books such as *The Natural History of Southern New Zealand* and being inspired by people like Anne Rimmer and my father, both of whom have published their works, I thought that I should 'give publishing a go'.

Unfortunately, I am a complete amateur when it comes to natural history. Perhaps my training as a doctor helps me a bit with scientific names, but I am very grateful to the scientists who checked whole chapters (sometimes more than one) for me, including Peter de Lange, Dylan van Winkel, Hamish Campbell, Bev Clarkson, Richard Taylor and a meteorologist who must remain nameless. I also received advice from Malcolm McLeod, William Benson (Philadelphia, USA), who gave me an overseas perspective, and my father, Bruce Hadden, who, despite being an amateur himself in this area, has a much better way with language than I do. No doubt there are

above **In the field with my children. Northeastern slopes of Mt Pirongia, Waipa District.**

still errors in the text; these I must take the blame for. I would also like to thank those who provided me with photographs and pictures and arranged for me to use copyrighted figures, including Paddy Ryan, Michelina Pratt, Simon Franicevic, Siobhan Smith, Dave Gunson, Lisa Hoskin, Brent Stephenson, Tony Edhouse, Margaret Low, Lindsay Hawke and Frances Nolan. Mike O'Rourke gave me a different perspective when he took me up in his plane for aerial photos. Thank you also to Margaret Sinclair and Anna Bowbyes and all the team at Random House, as well as Jane Meder for her drawings.

I also need to thank various institutions and companies, including the University of Auckland, the Department of Conservation, MetService and NIWA, Auckland Council, the Waitomo Museum of Caves and Waitomo Caves Discovery Centre, Landcare Research: Manaaki Whenua, and the Alexander Turnbull Library. Air New Zealand helped me unbeknown to them, since I took several photos from my seat whilst on my way to either Christchurch, to visit some of my wife's family, or Dunedin, where I occasionally teach and where I first started reading about natural history.

I should point out that I relied mainly on secondary sources, i.e. sources, usually books, that derive their information from elsewhere, although luckily I have access to the University of Auckland's online journal subscriptions, which has been extremely useful. Virtually none of the book is based on my original research.

NOTES ON THE TEXT

I have defined the upper North Island, or northern New Zealand, as that part of New Zealand that was designated as the Province of Auckland by the New Zealand Constitution Act of 1852. It includes all of the North Island and adjacent islands as far south as the mouth of the River Mokau. The southern boundary then runs up that river 'to its source, to the point where the Ngahuinga or Tuhua, the principal tributary of the Whanganui River, is intersected by the thirty-ninth parallel of South Latitude, thence Eastward by the thirty-ninth parallel of South Latitude, to the point where that parallel of Latitude cuts the East Coast of the Northern Island of New Zealand'. This equates to a line running just south of Lake Taupo and just north of Hawke Bay, minus a section in the southwestern corner the majority of which now falls in the Taranaki Region (or, in 1852, the 'Province of New Plymouth'). The Pureora Forest Park is within this boundary but the border is just to the west of it. An arbitrary definition, but one that suits the parts I know best and is all within a 5-hour, at most, drive of the largest city in the area, Auckland, where I happen to reside. As Alan Titchmarsh noted, when comparing England with North America, we are lucky that our country is small enough that we can get to know most parts well, yet varied enough to have a great diversity to explore.

To help the reader locate place names, I have usually named the administrative district or city in which the place referred to lies. For most places, I believe this works well.

UPPER NORTH ISLAND TERRITORIAL AUTHORITIES

There are two anomalies to the usual division of New Zealand into districts and cities in the north: the unitary authorities of Gisborne District and Auckland, the latter having no title (being called neither a city, district nor region). These two areas cover a larger area than other districts, so in places I have used other terms (e.g. 'the former Rodney District') to help the reader understand which area is being discussed. I have also occasionally referred to an administrative region (e.g. the Northland Region) if I wish to discuss a larger area, and have used the uncommon but useful term 'North Auckland Peninsula' to refer to that part of the mainland North Island which falls within the boundaries of Auckland and the Northland Region. Most other area names should be self-explanatory (e.g. Pureora Forest Park).

New Zealand English generally uses British rather than American spelling and I have followed that convention in this text. However, although 'sulphur' is the traditional British English rendition of that element's name, the American spelling of 'sulfur' has been gaining acceptance even in the United Kingdom (e.g. in GCSE exams) and is the official International Union of Pure and Applied Chemistry spelling. Hence I have spelt the element as 'sulfur' in this text.

I have tried to minimise my use of abbreviations, especially since some disciplines use different abbreviations from others. However, I have used the abbreviations Ma and ka for millions of years / millions of years ago and thousands of years / thousands of years ago throughout, as per the 'Convention on the use of units for time in Earth and planetary sciences'.

Finally, if you spot anything you think should be changed, if new information comes to light, or if you have any other comments or criticisms, please let me know. My email address is peter.h211@gmail.com. My greatest reward would be seeing people being interested in the information that I have collated and helping to make any second edition better!

CHAPTER ONE:

LANDFORMS AND GEOLOGY

INTRODUCTION

The upper North Island is a landscape both old and new. In the north and west, the land is older, consisting of sedimentary rocks laid down, in places, hundreds of millions of years previously. Volcanic rocks overlie much of the landscape, with large igneous plateaux scattered down the western coast of the North Auckland Peninsula. In the east, the rocks are similar to those in the north but have been forced upwards to greater heights by more recent tectonic activity, due to proximity to the boundary between the Indo-Australian and the Pacific plates.

Between east and west, from the Firth of Thames to the Bay of Plenty, the land has begun to rift apart, and in the larger rift, the Taupo Volcanic Zone, massive volcanoes have erupted volcanic material all over the Bay of Plenty. Smaller volcanoes unrelated to this activity have erupted in Auckland and Northland, and unconsolidated sediments have continued to fill in our coastline and the inland basins of the Waikato.

Before considering the specific geology of our area, we should first review how rock is made and the different types present here.

ROCKS AND MINERALS

By far the two most common elements in the Earth's crust are oxygen (46.6% of the Earth's crust by weight) and silicon (27.72%); other elements include, in descending order of abundance, aluminium, iron, calcium, magnesium, sodium and potassium and, more rarely, trace elements such as gold.

Minerals are the individual building blocks of rocks; they are defined as being composed of mixtures of atoms and molecules in a highly ordered structure with specific physical properties, formed by geological processes. They occur as crystals. Some minerals have very complex crystalline structures with many different atoms present, such as feldspars (each of which has, although complex, a definitive chemical composition and specific crystalline structure); while others are very simple, such as those made of just a single element (e.g. gold). Rock is the term used for a particular combination of minerals occurring together but without a definitive chemical composition. Rocks can be igneous (derived from molten magma), sedimentary (made up from sediments which have gradually accumulated over time, usually on the ocean floor) or metamorphic (altered by a period of time exposed to heat and pressure deep within the Earth's crust but without becoming molten).

Sedimentary and metamorphic rocks are, for the most part, formed from rock fragments (clastic sedimentary rocks) which originally derived from igneous rocks. Hence, it is perhaps appropriate to start with a description of igneous rocks and the minerals that form them.

IGNEOUS ROCKS

Igneous rocks are derived from magma welling up from deep inside the Earth which, if it reaches the surface, is called lava. Igneous rocks that derive from lava are called volcanic rocks; those that derive from magma that doesn't reach the surface but instead cools and hardens on its way up are called plutonic rocks. One has to go to the South Island to see large areas of plutonic rock exposed on land (the Median Batholith), although it does lie at depth off our western seaboard. There are some small areas in northern New Zealand where much more recent plutonic rocks are exposed on the surface: at Te Moehau on the Coromandel and on Cuvier Island to the northeast, where erosion has entirely removed the Miocene volcano and exposed the diorite magma chambers originally underneath the volcano, and at North Cape, where ultramafic rocks are exposed; Miocene volcanic 'dikes' also intrude into the basement rock in northern Great Barrier Island. Plutonic rocks are often quite different from volcanic rocks because they cool more slowly and hence the crystals within them are able to grow much larger than in volcanic rocks. As a result, they have a more coarse grain. However, in the north the majority of igneous rocks are of volcanic origin.

above **The basement of Parliament House (on the right) in Wellington is clad in Paritu quartz diorite from the Coromandel Peninsula. Wellington City.**

right **A quartz porphyry dike (on the right) intrudes into the pre-existing ('country rock') greywacke of the Waipapa terrane. At the southern end of Burrill's Bay, Great Barrier Island, Auckland.**

MINERALS

Silicates — minerals containing an anion consisting of silicon and (almost always) oxygen — are by far the most abundant minerals in the Earth's crust; 90% of igneous rocks are silicates. The simplest silicate is quartz, which is composed of only silicon and oxygen in the form of silicon dioxide (or silica SiO_2). However, the majority of silicates are based on the tetrahedral, negatively charged anion SiO_4^{4-}. This needs to be balanced by sufficient positively charged cations to maintain electrical neutrality.

Silicates can be classified according to their predominant cation as:

- ferromagnesian, which are dark brown in colour because of iron (Fe) and magnesium (Mg) cations, or
- non-ferromagnesian, in which aluminium (Al), calcium (Ca), sodium (Na) and potassium (K) cations predominate.

Ferromagnesian silicates include the dark green olivines (e.g. periodotite), which can vary from 100% iron silicate to 100% magnesium silicate, the pyroxenes (e.g. the black-brown augite), the amphiboles (e.g. the black hornblende), the micas and the biotites.

Non-ferromagnesian minerals are lighter in colour and include the feldspars as well as quartz, the latter being pure SiO_2 without any cation.

In general, as magma cools the first minerals to crystallise (at higher temperatures) are the darker, iron-rich ferromagnesians, although calcium-rich feldspars crystallise at relatively high temperatures too. Bowen's reaction series

describes the order in which crystallisation generally occurs: the first ferromagnesian mineral to crystallise is usually olivine (at 1200°C), followed by pyroxene, amphibole and then biotite mica; while, as mentioned, the first non-ferromagnesian minerals to crystallise are the calcium-rich plagioclase feldspars, followed by the sodium-rich plagioclase feldspars and then the potassium feldspar orthoclase. Muscovite mica and quartz crystallise at the lowest temperatures (around 700°C). Those minerals that crystallise early are termed mafic (for magnesium and ferric) and contain relatively more of the heavier elements, including magnesium, iron and calcium; those that crystallise late are termed felsic (for feldspar and silica) and contain relatively more of the lighter silicon, oxygen, potassium and aluminium.

Igneous and metamorphic rocks may also be described as either mafic or felsic. Mafic (basic) rocks, such as basalt, contain relatively more mafic minerals such as pyroxenes, olivines and calcium-rich feldspars along with a lesser amount of silica (basalt contains 45–55% SiO_2 by weight and is high in Fe, Mg and Ca but low in K and Na). Felsic (acidic) rocks, such as granite, contain relatively more silica and are dominated by minerals such as quartz and orthoclase (granite is commonly around 65–75% SiO_2 by weight and is rich in K and Na but low in Fe, Mg and Ca).

One can order volcanic rocks based on their silica content; that which has the lowest amount of silica (and hence is the most mafic) is komatiite; with increasing amounts of silica we get, in turn, basalt, andesite, dacite and rhyolite. Their plutonic equivalents are peridotite, gabbro, diorite, granodiorite and granite. The most mafic rocks, komatiite and peridotite, are termed ultramafics. With increasing silica content, rocks become lighter and more acidic, generally have a lower melting point and are more viscous when molten.

SELECTED SILICATES OF THE UPPER NORTH ISLAND

The tectosilicates: feldspars, quartz and zeolites

- Feldspars (characterised as $KAlSi_3O_8$, $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$) are the most common tectosilicates (framework silicates), i.e. those silicates that have a three-dimensional framework of silicate tetrahedra with all four oxygen atoms shared by neighbouring molecules. Feldspars make up as much as 60%

left **Igneous rocks, west of Cape Reinga and overlooking Te Werahi Bay, Far North District. These rocks, from the Northland Allochthon, consist of tholeiitic basalt (richer in silica and iron but poorer in aluminium than other basalts, from partial melting of peridotite (i.e. olivine and pyroxene) at mid-ocean ridges), andesite and spilitic lava (basaltic lava containing excessive sodium, due to sea water) in thick sheet flows; minor marine sediments are also present.**

of the Earth's crust; all contain aluminium as a cation, as well as potassium, sodium or calcium. The most common feldspars are the plagioclase minerals, containing calcium and sodium, which weather to clay and tend to be white or off-white in colour.

- Zeolites, found in Kawhia and the Taupo Volcanic Zone, are tectosilicates with water within their structure.
- Quartz (SiO_2) is one of the most common minerals in all rock types, although veins of pure quartz are rare. Such veins, however, do exist within the volcanic rocks of the Coromandel. Quartz has a white colour, such as one sees in the sands of Parengarenga Harbour.
- Feldspathoids, which resemble feldspars but have a lower silica content and a different structure, are rare.

Mica

The micas, which are either detrital or metamorphic, are 'sheet silicates'. They include muscovite (hydrous potassium aluminium silicate), a shiny, pale, flaky mineral; and biotite mica (hydrous potassium magnesium iron aluminium silicate), also very shiny. Grains of both can be found, albeit rarely, in greywacke sandstone in particular.

Augite

Augite, a type of pyroxene, is an essential mineral of mafic igneous rocks, with the chemical formula (Ca,Na)(Mg,Fe,Al,Ti)$(Si,Al)_2O_6$. The presence of the heavier metals imparts a darker colour to the rock compared with 'purer' silicates.

Olivine

Found in the basalts of Auckland and Northland, olive green and composed of magnesium iron silicate, olivine is common in both basalt and gabbro, the mafic igneous rocks, as well as being the main mineral in the ultramafic peridotites.

top **Almost pure quartz sands, Great Exhibition Bay on the eastern coast of the Aupouri Peninsula, Far North District.**

bottom **Auckland basalt scoria. Note the large pores where gas was once trapped. Pigeon Mountain, Auckland.**

Serpentine

A group of olive-green minerals found at North Cape and Piopio, as well as in boulders within the Northland Allochthon, these are 'hydrous magnesium iron phyllosilicates' with the chemical composition $(Mg, Fe)_3Si_2O_5(OH)_4$. As well as iron and magnesium (and, being hydrous silicates, silicon, oxygen and hydroxide ions), they may also contain minor amounts of chromium, manganese, cobalt and nickel. Areas where they outcrop, such as

North Cape, are notable for their distinctive flora.

Obsidian

Obsidian, also known as volcanic glass, is not very common but was important for early Maori, who used it to make tools. It is produced when felsic (silica-rich) lava extruded from a volcano cools rapidly with minimal crystal growth. The most important source was Mayor Island, with other deposits associated with the rhyolite domes of the eastern Coromandel. Obsidian is also found in some of the Kerikeri Volcanic Group. Glass has been made, on an industrial scale, from silica sands on both west and east coasts (the Kaipara area and Pakiri Beach).

NON-SILICATE MINERALS

Non-silicates comprise only 10% of igneous minerals, and include such minerals as hematite (Fe_2O_3), calcite (Ca_2CO_3) and other carbonates, halite (NaCl) and various sulfides (for instance copper, zinc and lead sulfide).

Although for completeness I am mentioning the non-silicate minerals at this point, many are predominantly found in sedimentary rock.

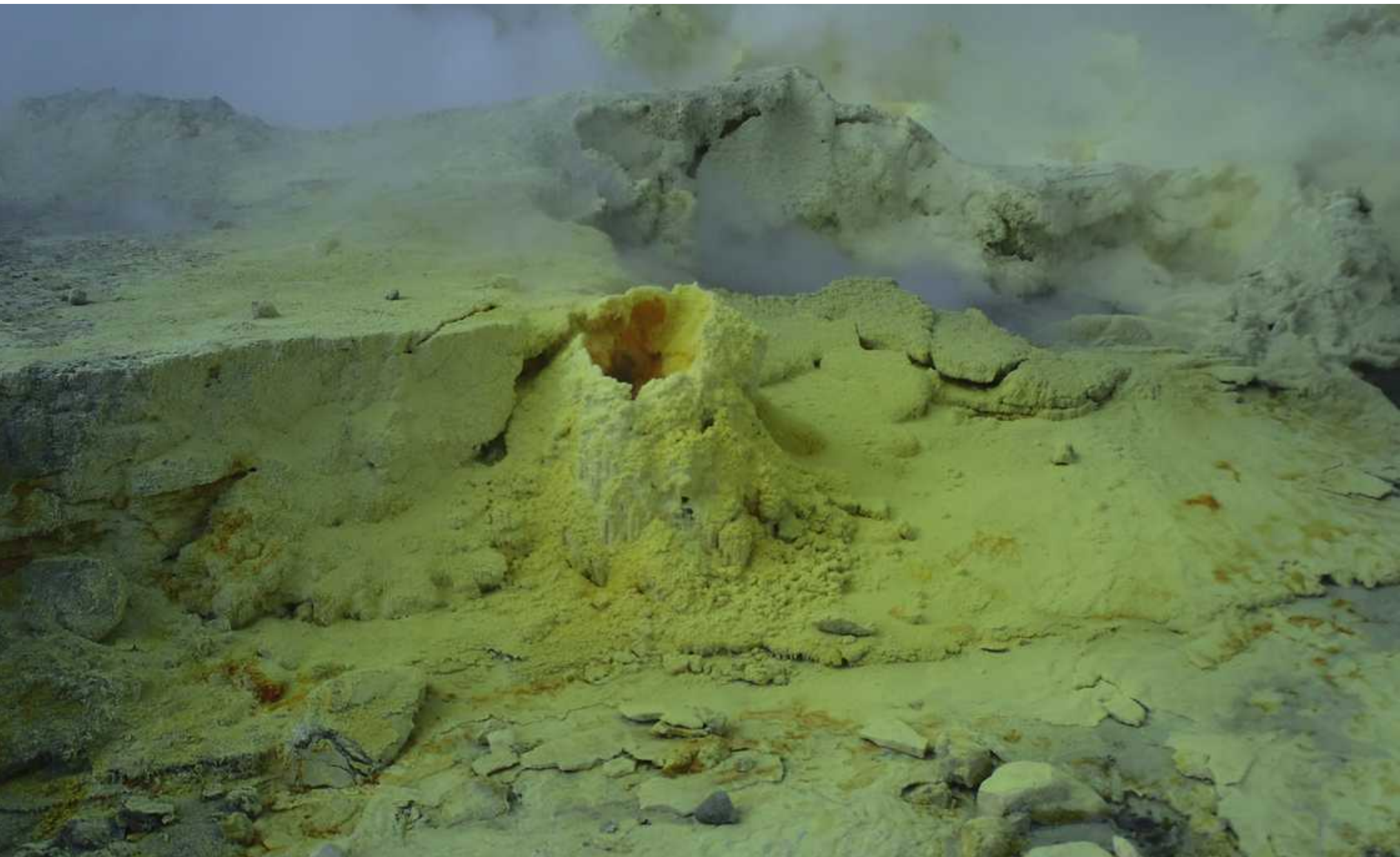
Carbonates

The second most common type of mineral after silicates, these are usually found in sedimentary rocks although there are very rare igneous forms. They are made up of oxygen and carbon (carbonate) together with a cation; the most common carbonate is limestone (calcium carbonate, $CaCO_3$).

Other non-silicate minerals

Other, rarer, minerals include sulfates, phosphates, sulfides, halides, oxides, hydroxides and certain native elements (mercury, gold, copper, silver and sulfur).

below **Sulfur coating a vent, in the crater of White Island, Whakatane District.**



VOLCANOES

Volcanoes can be described by the type of rock that they are mostly composed of, which is determined by the temperature at which they erupt. The appearance, or physical characteristics, of volcanoes reflects their chemical characteristics because different lavas erupt in different ways and hence produce different landscapes.

Rhyolitic magma is relatively cool, and only minerals that have a sufficiently low melting point will liquefy; it becomes silica-rich as a result. It is a thick, sticky lava that tends to cause large, explosive eruptions because of its stickiness, and gives rise to light-coloured rock because of its high silica content. Rhyolitic volcanoes include the huge calderas of Taupo and Rotorua as well as the domes associated with them, such as Tarawera and Ngongotaha.

At increasingly higher temperatures, lava becomes darker and more fluid, with more iron- and magnesium-containing minerals melting into it; the hottest, darkest and most fluid lava of our volcanoes is basaltic. In between are the intermediate andesitic and dacitic volcanoes.

BASALTIC VOLCANOES

Basaltic volcanoes are formed by melting (technically, fractional melting) in the hot (1000–1500°C), fluid asthenosphere, the layer below the Earth's crust and uppermost

above **Mount Edgecumbe — a dacite cone of the Taupo Volcanic Zone, rising above the subsiding, earthquake-prone Rangitikei Plains, alluvial plains which fill the coastal part of the Whakatane Graben, Whakatane District.**

above **St Paul's Church, Paihia, built of Kerikeri Volcanic Group basalt quarried near Kawakawa, Far North District.**

mantle, generally starting at 100–350 km below the surface. At these temperatures the rock eventually produced tends to be basaltic; volcanoes of this type tend to contain less dissolved gas and therefore the eruption is less explosive when the magma decompresses on hitting the air. These volcanoes are generally smallish, made up of scoria cones and lava forming a gently sloping shield volcano; Auckland's emblematic Rangitoto Island is such a volcano. When active, there would have been a fiery fountain in the crater with glowing rivers of lava cascading downhill.

On the way up, some minerals — particularly those rich in calcium, aluminium, magnesium and iron — can crystallise out (crystalline fractionation) and crustal rocks adjacent to the rising magma may be melted into it (crustal assimilation), altering the rock so that what remains becomes richer in silica and more andesitic, dacitic or rhyolitic. This tends to happen most frequently above a subducting plate.

ANDESITIC AND DACITIC VOLCANOES

Andesitic volcanoes are probably what most people think of when they imagine a volcano, as they have a large, sloping conical form and a crater at the top. They are usually the product of a subduction zone; the mantle just above the descending crust melts and then ascends as magma into cracks and faults in the crust. Usually there is a magma chamber a few kilometres below the surface, into which crustal rock also melts. Both magma and melting crustal rock give off gases, especially water vapour, causing an increase in pressure until the ground above can no longer keep a lid on it and it erupts. These volcanoes usually eject both volcanic ash (rock fragments) and lava, forming composite (layered), cone-shaped mountains. The original basaltic melt material is usually represented by volcanic glass and tiny crystals, with larger crystals embedded within it, commonly of plagioclase, pyroxene and titanomagnetite. Some also contain olivine or hornblende, the exact composition depending on the crystal fractionation, crustal assimilation and other mixing that went on. Fragments (xenoliths) of

country rock, the rock that was there before the volcano erupted through it, are also usually present.

Andesitic volcanoes erupt sporadically; after a while, a plug then forms in the vent, only for the volcano to erupt again when the pressure below exceeds the weight of the material in the vent.

Mounts Taranaki and Ngauruhoe, in the central North Island, as well as Japan's Mt Fuji, are examples of andesitic stratovolcanoes; these tall, conical volcanoes erupt periodically and build up a cone of many different layers (strata); the lower

above **Maungaroho, on the eastern shores of the Kaipara Harbour, is an eroded andesitic intrusion. Note the columnar jointing. Kaipara District.**

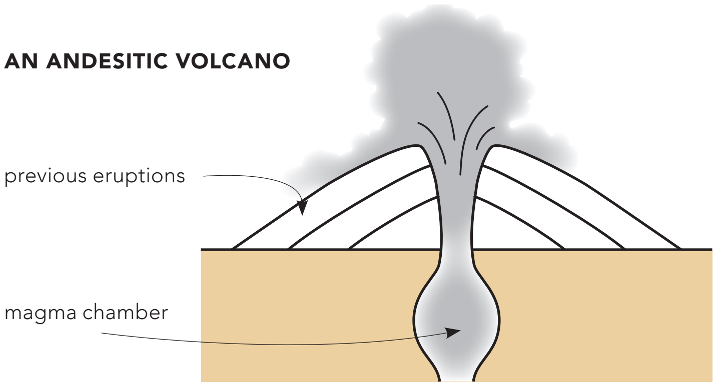


Figure 1 **An andesitic volcano builds up layers of volcanic ash and rock into a conical cone, fed by a magma chamber underground.**

above **Bald Rock near Kaiwaka is formed from exfoliation of jointed dacite lava. Kaipara District.**

viscosity of the lava allows a larger volcano to be built up. The Miocene volcanoes of Northland and the Coromandel are mostly andesitic although, thanks to erosion, they have lost their original shape.

Dacitic volcanoes are very similar to andesitic volcanoes, except that their lava has a higher silica content; there are two recently active dacitic volcanoes in northern New Zealand, Mounts Edgecumbe and Tauhara, both in the Taupo Volcanic Zone (TVZ). An older example of a mainly dacitic volcano is Little Barrier Island, in the still active Hauraki Rift. However, many volcanoes have erupted more than one type of lava — White Island and Maungatautari have erupted both andesitic and dacitic lavas, while Mounts Karioi and Pirongia are eroded stratovolcanoes with an andesitic superstructure on top of a basaltic shield volcano; Tarawera has erupted both rhyolitic and basaltic lava. Andesitic volcanoes tend to produce short flows of blocky lava that flow gently down the volcano's flanks; dacitic stratovolcanoes are more commonly explosive, producing tephra and pyroclastic flows.

RHYOLITIC VOLCANOES

Rhyolite magma is the product of crustal melting of andesitic rock; the later volcanoes (less than 12 Ma) of the Coromandel and the most prominent eruptive centres north of Tongariro in the TVZ are rhyolitic. The rhyolitic eruptions of the Coromandel probably occurred due to heating and melting of the crust from the previous andesitic eruptions as well as because of crustal extension, and the initial Taupo eruptions (and some later smaller ones) were also andesitic rather than rhyolitic. Rhyolitic magma is silica-rich, and this high silica content makes it viscous. If it is also gas-rich, a rhyolitic volcano can erupt explosively as the magma reaches the Earth's surface and depressurises, causing the dissolved gas to suddenly rush out of solution. These volcanoes tend to erupt every 1000 years or so, rather than every few decades as is common for andesitic volcanoes. There are two main types of rhyolitic volcanoes:

- Rhyolitic caldera volcanoes occur when there is a very large crustal melt and the viscous, oozing, relatively cool rhyolitic magma does not erupt fast enough to relieve the pressure of the large amount of gas and steam within it. Massive 'pyroclastic' eruptions ensue, with huge clouds of debris being hurled kilometres into the air, and fast-flowing 'pyroclastic' flows of gas and burning rock (tephra) spread out from the vent, hugging the ground and initially moving near to the speed of sound — too fast to escape from. If the lava and ash weld together into a solid rock as the flow cools, the result is ignimbrite; if they don't, one gets volcanic breccias. It is worth noting that the term 'ignimbrite' was coined by a New Zealander, Patrick Marshall, from the Latin *igneus* (fiery) and *imber* (heavy rain shower). It is a very poorly sorted mixture of volcanic ash (glass and crystal fragments) and small pumice stones (lapilli), with scattered fragments of other rocks. Ignimbrites may be

loose and unconsolidated, or solidified rock (welded tuff). As so much magma gets ejected from the volcano, the roof of the magma chamber becomes unsupported and the whole land slumps, forming a shallow crater or caldera kilometres across. Lake Taupo is such a caldera; if, like Taupo, the caldera fills with water, the first event in the next eruption will be the sudden generation of superheated steam as the magma hits the water, creating an even more violent phreatomagmatic eruption (similar to the eruption of Krakatoa in 19th-century Indonesia).

- Rhyolitic dome volcanoes also form from melting crust 5–10 km down, with similarly very viscous and relatively cool (i.e. rhyolitic) lava. They can be explosive, but if the lava is relatively low in gas when it reaches the surface it will form a steep-sided dome instead of spreading out over the land like a stratovolcano would. With repeated eruptions more lava builds up in the dome, forcing previous layers out like an onion, and the top becomes domed or flat with steep sides. The volcano can continue erupting for years, but when it erupts again the vent is usually in a different place. Examples of such volcanoes are Rotorua's Mounts Ngongotaha and Tarawera as well as Mt Maunganui (Mauao) in Tauranga.

top **Ignimbrite from a Taupo Volcanic Zone eruption that reached Auckland, hundreds of kilometres away (Puketoka Formation). Farm Cove, Pakuranga, Auckland.**

middle **The Aldermen Islands, off the eastern coast of the Coromandel Peninsula, Thames-Coromandel District, are remnants of a volcanic complex of rhyolitic domes, ignimbrite and breccia that started erupting 5–6 Ma. On the left is Middle Island, with pinnacles and stacks determined by columnar jointing, while The Spire in the centre background has steeply inclined fractures which control its shape.**

bottom **The snow-covered Mt Tarawera towers over Lake Tarawera, around which forest has regenerated from scratch over 123 years (photo taken in 2009). Rotorua District.**

SEDIMENTARY ROCKS

Sedimentary rocks may only represent 5% of the rocks in the Earth's crust, but they comprise 75% of those that outcrop on the planet's surface. Sedimentary rocks are deposited rather than erupted onto the surface of the Earth, by a multitude of different means.

CLASTIC SEDIMENTARY ROCKS

The most common form of sedimentary rock is clastic, meaning that they are the product of erosion and subsequent deposition elsewhere of older rocks and are composed of solid bits (clasts) of those older rocks; these may also be termed detrital or allochthonous sediments. The original rock type does not have to be sedimentary — often they are of igneous origin, e.g. volcaniclastic rocks — and sedimentary rock most frequently derives from rocks on dry land that were gradually eroded away by wind and rain and then transported by rivers (fluvial sediments) and sea currents off the land and out to sea. Once these fragments are in the sea, they gradually fall down the water column and settle along beaches and estuaries, as well as further out on the sea floor or in ocean trenches, in flat layers (strata). This gives rise to the characteristic layered appearance of many sedimentary rocks.

Initially just loose particles ('unconsolidated' sedimentary rocks), over time — usually as a result of being buried under other, later rocks — these layers are gradually compressed together with a 'matrix' of smaller particles. Normally, minerals precipitate (as iron, aluminium or silicon compounds) in the pores to form cement until the layer turns into solid rock (i.e. becomes consolidated); very fine-grained sedimentary rocks such as shale do not require cementing

top **Clastic sedimentary rocks of the Pakiri Formation (Waitemata Group), which is dominated by alternating beds of coarser sandstones and finer siltstones, now uplifted above sea level. Southwest Kawau Island, Auckland.**

bottom **Unconsolidated recent sediments; fluvially deposited clasts, surmounted by volcanic andesitic tephra from the Tongariro volcanoes, on our southern border. Tongariro River, Taupo District.**

agents, as the clay particles simply cling together under the pressure of burial. Tectonic forces occurring subsequent to deposition may compress or stretch these layers so that they become folded and fractured, but the original layered texture of sedimentary rocks is still usually observable. Dead animals and plants are trapped in these sediments as they form and become fossils; one can sometimes date rocks based on the fossils they contain.

For these submarine sediments to become visible on the surface, either the crust has been uplifted or sea levels have fallen. Some sediments may also be pushed sideways into a convergent plate margin, usually an ocean trench, by movement of the sea floor towards such a margin; being lighter than the oceanic crust, they get scraped off the descending plate to form an 'accretionary prism' of sedimentary rock at that location, as happened to our greywackes (see below), before being pushed up to form land.

Larger chunks of sediment, such as pebbles and sand, generally will not be carried as far out to sea as smaller ones, such as silt; this means that the presence of rocks such as sandstones often indicates that at the time of their deposition a more near-shore environment existed, as opposed to siltstones, which were usually carried further out to sea. This is of course not always true: the sheltered, shallow harbours of our west coast are filled with silt because they are so calm that even small particles can drop out of the water column. Alternating sandstone and siltstone beds may indicate a fluctuating sea level due, for instance, to repeated episodes of uplift and subsidence, bringing the coast closer or further away. Well out to sea one may find rocks devoid of terrestrial sediments; a common rock type deposited there is limestone, the product of millions of marine organisms.

Not all clastic sedimentary rocks come from ocean-floor deposits, although most do. Some river-derived (fluvial) sediments may not make it all the way to the sea but instead accumulate in inland basins (such as the recent Tauranga Group alluvium that fills the Waikato Basin and the Manukau Lowlands), estuaries and lakes; in time, almost all lakes will gradually fill in with sediment eroded down into them from higher ground and dead vegetative material that builds up within them. Rocks formed in these areas will be characterised by freshwater as opposed to marine fossils. Sediment can also accumulate subaerially without requiring river transport, e.g. by the wind blowing sand into dunes (aeolian sedimentation); this type of landform is readily observable along our west coast.

As a result of these differences, the type of sedimentary rock present and the fossils within it can tell us a lot about where the rock must have been formed and how long ago this might have happened. Sophisticated dating methods, using 'natural clocks' such as the decay of radioactive elements, can also be used to date rocks more exactly.

Clastic rocks are classified based on the size of particle present. From large to small, these types are outlined below.

CONGLOMERATE

Conglomerate is the term given to sedimentary rock made up of clasts 2 mm or greater in diameter (gravel) that have become stuck together in a matrix of smaller rock particles, as opposed to gravel which is unconsolidated. The component rocks have been smoothed off by erosion on the way to their final destination and have often been sorted by water, for instance if they have been part of a boulder beach. This rock type may be seen around the Waitakere coast, where the boulders are igneous in origin.

BRECCIA

Breccia is a rock made up of irregular broken

fragments of minerals and rocks held together by a fine matrix. The rocks have irregular and uneven edges, as usually they have not travelled far from their point of origin and therefore have not become smoothed off as in conglomerate. Breccias can have a wide variety of different origins.

SANDSTONE

Sandstones are rocks made of sand particles, i.e. particles that are between 0.1 and 2 mm in diameter; they are basically hardened sand. The grains can be of many different minerals: greywacke contains quartz, feldspar and rocky fragments; quartzite is the name given to sandstone if more than 90% of the grains are made of quartz.

MUDSTONE

Mudstone is used in New Zealand as a general term for rock made of particles mostly less than 0.1 mm in diameter; it is mud hardened by time into rock, and hence is often weak and prone to landslides. It almost always occurs with sandstone, forming separate beds. One can use the term 'siltstone' for rock which is predominantly composed of silt particles (0.004 to 1 mm in diameter). The soft blue mudstone common in the North Island is often referred to as papa.

ARGILLITE

Argillite is a hardened, slightly recrystallised (i.e. mildly metamorphosed) mudstone and is used for aggregate in the construction industry. It is usually seen as dark black bands within grey greywacke sandstone (see below); coloured argillites are also visible at the Three Kings, Whangaroa Bay, the Bay of Islands and the Hauraki Gulf islands; red and green colours occur in the presence of iron-bearing minerals.

NON-CLASTIC SEDIMENTARY ROCKS

Although less common, not all sedimentary rocks are composed of bits of older rocks transported from elsewhere. Some, such as coal, oil and gas deposits and many limestones, are simply the remains of various plants and animals (bioclastic sediments). Others are formed by biochemical and chemical processes such as precipitation. Such rocks can be grouped together as 'autochthonous', since they are produced in the same basin in which they are deposited, rather than being transported from somewhere else, although the distinction may sometimes be somewhat artificial.

LIMESTONE

Limestone is any rock containing more than 50% calcite or aragonite (crystals of calcium carbonate). In the north, fossil bryozoans and bivalves are the most abundant source of limestone, their shells, of which calcium carbonate is the main constituent, eventually ending up on the ocean floor. Limestone may also be formed from secretions of algae, and calcium carbonate previously dissolved in water can be precipitated out to form the limestone varieties travertine or tufa (see below). If a rock contains less than 50% calcium carbonate we call it 'calcareous' — e.g. calcareous sandstone — but not limestone. Limestone is soluble in weak acid solutions, which leads to the formation of caverns and karst landscapes through which underground rivers may run, such as at Waitomo.

Most of our limestone, present in Waitomo, Northland and south of Gisborne as well as, to a very limited extent, Auckland, was buried under other sediments and subjected to pressure. If buried under more than 200 m of sediment, some carbonate minerals become more soluble, so dissolve in places subject

opposite top **Coarse volcanic breccia. Karekare Beach, Auckland.**

opposite middle **Waitemata Sandstone cliffs, Whangaparaoa Peninsula, Auckland. The layers of sandstone and mudstone were deposited horizontally, but slumping and upheavals in the north part of the Waitemata Basin have deformed them.**

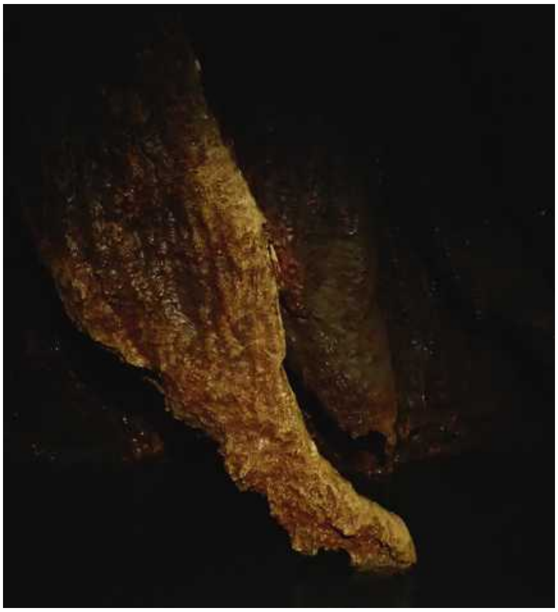
opposite bottom **Soft mudstones predominate on the inland route between Wairoa and Gisborne (Mangaheia Group); sandstones are also present. Gisborne District.**

top **Fallen stacks of limestone slabs (of the Papakura Formation, a coarse rock containing pebbles, shells, grit and sand) resting on Hunua-Bay of Islands terrane greywacke (sandstone and argillite). Motuketekete Island, Hauraki Gulf, Auckland. Note the marked layering of the limestone slabs; the more erosion-resistant and therefore protruding layers are made of shells, separated by layers of sand.**

bottom **Travertine-coated caves at Waitomo, Waitomo District.**

top **A bioclastic speleothem, Ruakuri Cave entrance, Waitomo District. This is formed from chemically deposited limestone on which moss has grown and become incorporated into the 'stalactite', causing it to have a curved lower end pointing towards the sun.**

bottom **Sinter has been deposited from a geothermal spring close to Lake Rotomahana to form a miniature version of the Pink and White Terraces; it has also been partially covered with algae and bacteria. Waimangu, Rotorua District.**



to pressure and then reprecipitate in pores, becoming calcite cement (pressure solution). However, there are areas (e.g. around Motuihe Island) that were buried less deeply and where fossils are readily visible; there are other areas (e.g. Waitomo) where the limestone was buried even more deeply (1–5 km) and thus has a 'flagged' appearance.

Limestone is used in the manufacture of cement, as well as for agricultural lime and road aggregate; some is also used for decorative work, particularly on buildings. The Portland cement works near Whangarei supplies more than 50% of New Zealand's needs from nearby quarries of Mahurangi and Whangarei Limestone. Limestone is also mined from Te Kuiti Group rocks in the Waikato, and in the Gisborne District is obtained from Miocene and Pliocene rocks (for aggregate and agricultural use). Lime has also been sourced from the shell beds in Auckland's Waitemata and Manukau harbours.

CHERT

Chert is a rock type composed mainly of the mineral chalcedony, a cryptocrystalline form of silicon dioxide which is also found in sinter. It is often very hard and erosion-resistant and can be almost any colour from orange to blue, black and white. The silica in chert associated with limestone is predominantly derived from the skeletons of small marine organisms including diatoms, radiolarians and sponges. Chert may also be derived chemically (see below), from precipitation of dissolved silicon. Chert is used for aggregate, because of its hardness.

above **Karamuramu Island, Auckland, made almost entirely from chert and quarried to provide the red pavements seen in Auckland's older suburbs.**

COAL AND LIGNITE

These sedimentary rocks derive from dead plant (organic) material. Such vegetation starts out as the peat of freshwater bogs before turning into lignite (brown coal) over time and under the pressure of burial. Lignite can be found within the sands of the Aupouri Peninsula. Lignite becomes coal when water and volatile hydrocarbons are expelled by even deeper burial.

Coal is an important economic resource, but the burning of coal is also a major source of greenhouse gases. Presently, the Waikato is the North Island's only coal-producing area, with the largest production taking place in the Rotowaro coalfield near Huntly. An estimated 508 megatonnes of coal exist in the Waikato Coal Measures of the Waikato and northern King Country. Near Huntly in the north Waikato are our largest coal mines, extracting sub-bituminous coal from the Late Eocene and Oligocene Te Kuiti Group; coal deposits further south tend to be more sulfurous, a consequence of the depth of the seams under marine sediments. Coal contains a greater amount of energy per unit volume, but peat and lignite can also be commercially useful and peat is being commercially mined in the Hauraki Plains at present.

There also exist, in north Taranaki and the southern King Country, the Taranaki coalfields, which contain non-bituminous coal in rock of Early Miocene age (the Maryville Coal Measures).

OIL

Oil is also a product of dead organic material. Seeps of oil are common in the eastern Raukumara Peninsula with some elsewhere, including a few in the far north. The presence of these oil seeps in conjunction with sandstones in the Wairoa area has periodically given rise to hopes of commercially viable quantities being found — sandstones being able to trap oil within their pores and cracks. The first commercial discovery of oil in northern New Zealand was made in 1998 at Kauhauroa, 10 km northeast of Wairoa.

Given the presence of offshore oil in the Taranaki Basin, there have been attempts to locate similar reserves in the Hamilton Basin as well as further north along the west coast of the North Auckland Peninsula, as it is thought that the Northland Basin is really just an extension of the Taranaki; exploratory drill holes to date

left **North New Zealand's first commercial oil discovery. Kauhauroa, Wairoa District.**

have found minimal hydrocarbons but did reveal the presence of Te Kuiti and Waitemata rocks at depth in the Hamilton area.

KAURI GUM

Another organic sedimentary rock, kauri gum deserves mention because from around 1800 to 1920 it was a major source of income in Northland, being used for varnish and in the production of linoleum until synthetic alternatives became available. It is found in many parts of kauri's former range, usually in Late Pleistocene and Holocene alluvium and swamp deposits.

TRAVERTINE, TUFA, SINTER AND OTHER CHEMICAL SEDIMENTS

Solutes in salt-rich water, such as geothermal waters or water running through limestone caves which have picked up a lot of calcium carbonate, may precipitate out to form sedimentary rock, for instance when the water cools and is no longer able to carry as much solute in solution.

Two of these rocks are types of limestone, travertine and tufa, formed from chemical precipitation of calcium carbonate from either cold or hot water (hot water works better). Travertine forms a hard and impermeable covering on other rocks and makes up the stalactites, stalagmites and flowstone coatings of the Waitomo Caves; it also precipitates around cold and hot springs. Tufa, conversely, is porous and contains more impurities; it often precipitates around cold springs.

Another such rock is sinter or, more specifically, siliceous sinter or geyserite (to distinguish it from calcareous sinter or travertine). This is a multi-coloured rock usually precipitated from hot geothermal water rich in dissolved silica. It also forms a coating on other rocks, with algae, bacteria and other micro-organisms in the water also contributing to its colour. It is found in geothermal hot springs of the TVZ at Waimangu and Waiotapu as well as in hot springs associated with major faults, such as at Mohaka. The most famous example in northern New Zealand were the Pink and

above **The White Terraces (Charles Blomfield, 1884), prior to the eruption of Mt Tarawera in 1886. Image reproduced courtesy of Alexander Turnbull Library, Wellington, New Zealand. Ref: G-472.**

White Terraces near Rotorua, now buried by sediment beneath Lake Rotomahana following the eruption of Mt Tarawera in 1886. These terraces were made by two large geysers erupting hot water containing high concentrations of silicic acid and sodium chloride; the silica precipitated out on a base of layers of volcanic fallout.

The other group in this category, evaporites, are not found to any substantial degree in the north; they are formed from trapped sea water that then evaporates, leaving behind its salts. The first to precipitate is calcite (calcium carbonate, limestone), followed by gypsum (calcium sulfate), rock salt or halite (NaCl) and finally potassium salts (potash) such as KCl, KOH and others.

METAMORPHIC ROCKS

Metamorphic rocks are those that have been altered by a period of time spent deep enough in the Earth's crust to be exposed to sufficient heat and pressure to change them and their minerals into different structures — a process called 'recrystallisation' — but not quite enough to melt them.

Metamorphic rocks, such as schist, are common in Otago but rare in the north — there is some schist just to our south in the Kaimanawa Range. Greywacke, although usually considered a sedimentary rock, has undergone a mild degree of metamorphosis so that it is harder than the more recent sedimentary rocks which in places cover it. An example is the hard rocky greywacke coast of Waiheke Island compared with the crumbly cliffs of mainland Auckland. Marble is the metamorphic form of limestone.

METALS

Metals can be present either as a single element, e.g. gold, which is very non-reactive, or as part of a more complex molecule (we have already met the most common ones — aluminium, iron and magnesium — in our discussion of silicate minerals). Several metals can be found in northern New Zealand and have been exploited to varying degrees.

Epithermal (or hydrothermal) gold can be found in the Coromandel and Kaimai ranges, where it was deposited by geothermal systems associated with the volcanic activity which occurred there from 12 to 3 Ma. These deposits are extremely important economically and were particularly so in the 19th century. In such deposits, mineral-laden hot water was pushed up from below and found its way to the surface through cracks in the rock. As it cooled, the dissolved minerals were precipitated out to line these cracks as gold–silver–quartz veins, as well as other minerals. The same process, with deposition of metallic ores, is also active in modern geothermal systems including the Champagne Pool at Waiotapu near Rotorua.

Other metals found with gold in these deposits include silver, lead, mercury, copper and zinc; the anions associated with them may also have value, such as the sulfides in the Coromandel. Manganese, usually deposited originally as nodules on the sea bed, is associated with red chert, jasperite and spillite in the Waipapa terrane and is frequently present within this from the far north's Whangaroa Bay to the Hunua Ranges. It can also be found, unrelated to the Waipapa terrane, in the Waitakere Ranges. Manganese is of particular interest as it was the subject of

right
Abandoned copper mine. Kawau Island, Auckland.

above **The ironsands of our lower west coast. Karekare Beach, Auckland.**

the first European mining operation in New Zealand, in 1842 on Kawau Island. During mining, copper was discovered incidentally in a quartz vein and also successfully mined.

Other volcanic areas have also produced metals of commercial value. Copper has been mined in Tangihua Formation rocks near Kaeo and Whangarei, and sinter has been mined for mercury in Ngawha and Puhipuhi in Northland as well as in the Coromandel; it is also present around the northern Waikato's Lake Waikare. Deposits of bog iron, formed from leaching of ferrous iron from Kerikeri basalts and subsequent deposition at the surface, have been mined, especially around Okaihau and Kamo in Northland. Bauxite has been also found in the Far North District between Kerikeri and Kaeo, leached in a similar fashion from the same basalts.

Even cold mineral springs, common in the Gisborne District, carry water with much higher concentrations of dissolved chemicals compared with rainwater (meteoric water). Sometimes this can be a problem — for instance, there is a significant concentration of arsenic in the Waikato River, due to hot-spring discharges into its tributaries, and this does affect the life within the river. The types of minerals present, and the deposits they leave when they precipitate, can all be used to determine the source of the chemicals in the water and the conditions under which they were deposited.

Finally, no description of our metals would be complete without mention of one of our currently most important resources, the ironsands of the west coast Karioitahi Group. These are mined and then smelted to produce iron at Glenbrook Steel Mill. Titanium is also present within these and other sands (e.g. on the east coast of the Coromandel and at Matakana Island), although it has not, as yet, been significantly exploited.

A GEOLOGICAL TIMELINE

The landscape we know today is a product of the sedimentation, folding, volcanism and erosion that have taken place over many millions of years. However, its outline on a map, including all our current bays and headlands, has only been determined in the last 10,000 years, when sea levels rose to around their current level at the end of the last glacial period (colloquially referred to as the 'Ice Age', although a visit to Antarctica would convince any observer that we are still in an Ice Age, just a warmer interglacial). We don't often see the underlying rocks, covered as most of them are by soil, vegetation and water, but it is the bedrock that is the basis of our landscape and its topography — and it is the bedrock's topography that to a large extent determines the inhabitants of the landscape, animal, plant and human, as well as the uses to which it is put. Good places to observe bedrock are on cliffs, road cuttings and by the coast, where the cover has been stripped off.

Geologically speaking, New Zealand is not an oceanic island. Oceanic islands are usually relatively transient and volcanic, whereas we exist on our own small piece of continental crust. This makes our geology much more like that of the larger continents than the neighbouring Pacific Islands — except for New Caledonia, which is also a part of our little continent.

Geologically, the upper North Island shares many similarities with the rest of New Zealand, but it also has its differences. Although it is perhaps true that the South Island holds New Zealand's most awe-inspiring geological scenery, the north has many varied geological features and is certainly as interesting to the observer as the rest of the country.

It is useful to think of the geology of our area as consisting of the following.

1. The basement rocks, the oldest rocks of all and which underlie everything else; in the north they are predominantly of 'greywacke'. These sedimentary rocks were laid down in a marine environment more than 110 million years ago (Ma), compressed by being buried quite deeply and hardened by that experience; they were then uplifted to form the underlying backbone of our land. They outcrop in our west and east, in Northland and the west Waikato as well as in the Gisborne District and the eastern Bay of Plenty, but have been smothered by volcanic rocks in the central North Island.

2. The more superficial and often softer sedimentary rocks of the Tertiary Period and the Late Cretaceous (see Fig. 3); rocks formed less than 110 Ma are included in this category. They were laid down in the sea over the top of the basement rocks but have since been eroded away to greater or lesser degrees. In some locations there are many layers of these rocks, but in other parts all have been eroded away to leave the basement rocks exposed. The north has much more remaining Tertiary rock than the South Island, with its more mountainous terrain and consequent greater erosion.

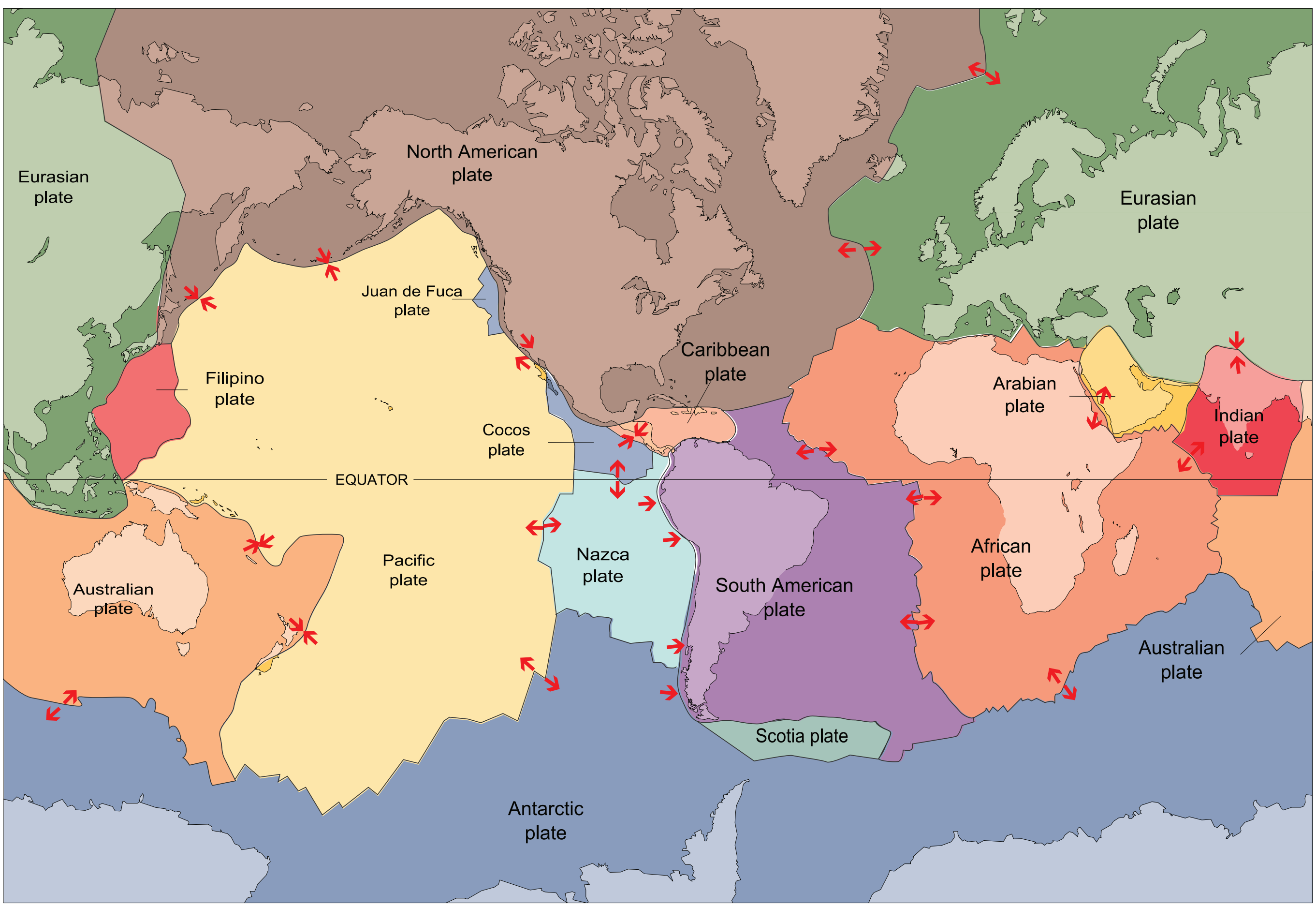
3. The volcanic rocks, mostly of the last 23 million years — in geological terms the recent past. Most are a result of an active plate boundary becoming present in our vicinity.

4. Alluvium, i.e. the very recent unconsolidated sediments such as sand and mud that have been washed down from our hills or pushed up by wave action onto our shores. Having not yet been subject to uplift and other movements of the Earth, these areas are generally relatively flat and include the sand of our beaches, the mud of our harbours and estuaries and the flat riverine plains in the basins where much of our most economically productive land lies.

We are still on the move, because of our position beside one of the Earth's great crustal collision zones. Underneath us is the Indo-Australian Plate but, not far to the east, just offshore of Gisborne and East Cape, is a plate boundary where the Pacific Plate is sliding (subducting) under the Indo-Australian Plate.

As the Pacific Plate descends under the Indo-Australian and therefore under us, it pushes our land up and has lifted the majority of the North Island out of the water in just the last few million years. Because the plate boundary is closest to the Gisborne District, the hills of the Raukumara Range and Te Urewera are steeper than those in the more subdued landscape of Northland. Earthquakes are also more common in the east than in the part furthest from the plate boundary, namely the North Auckland Peninsula. The subduction has also led to volcanism, still actively occurring in the TVZ.

Figure 2 **The Earth's plates. New Zealand's North Island sits on the Indo-Australian Plate, with the subducting Pacific Plate lying off our east coast. Image reproduced courtesy of the United States Geological Survey.**



ERA	PERIOD	EPOCH	DATES	
Cenozoic	Quaternary	Holocene	12 ka to present	The current period. Volcanic eruptions continue in Auckland and the Taupo Volcanic Zone (TVZ)
				Formation of the modern coastline and alluvial plains as sea levels rise to their present level
		Pleistocene	2.6 Ma–12 ka	The 'Ice Ages'. Multiple episodes of warming (interglacials) and cooling (glacial periods) with sea-level rise and fall
				Volcanic eruptions in Auckland, Northland and the TVZ
	Neogene (Tertiary)	Pliocene	5–2.6 Ma	Gradual cooling as the Earth approaches the 'Ice Ages'
				The last volcanic eruptions in the Coromandel and Waikato
				Raukumara Range becomes subaerial (3 Ma)
		Miocene	23–5 Ma	Volcanic activity in Northland, the Coromandel and the Waikato
				New Zealand continues to lift out of the sea
				Rifting begins between Northland and East Cape (20 Ma)
				Deposition of sediments in the Waitemata, King Country and Taranaki basins
				Emplacement of the Northland and East Cape allochthons (24–21 Ma)
	Palaeogene (Tertiary)	Oligocene	38–23 Ma	New Zealand maximally submerged around 23 Ma
				Subduction zone becomes active in our region around 25 Ma with the onset of uplift
				Final stages in the deposition of Te Kuiti and Mangatu Group rocks
		Eocene	55–38 Ma	Global temperature maximum occurs during this epoch; global cooling begins after this
				Rocks of the Northland and East Cape allochthons finish forming
				Continuing submergence and deposition of Te Kuiti and Mangatu Group rocks
		Palaeocene	65–55 Ma	Continuing submergence and deposition of Mangatu Group rocks (Gisborne District)
				Rocks of the Northland and East Cape allochthons continue forming

Figure 3 **A timeline of New Zealand's geological history. The time period from the explosion of different multi-cellular life forms in the Cambrian is divided into three eras: the Palaeozoic (literally, ancient life), Mesozoic (middle life, the time of the dinosaurs) and Cenozoic (recent life; on a planetary scale the age of mammals, although in New Zealand more properly it should perhaps be the age of birds). Each is further subdivided into various periods and epochs, the boundaries between each representing major events such as extinctions (e.g. at the end of the Triassic) or climate change (the start of the Pleistocene, known colloquially as the 'Ice Ages').**

Mesozoic	Cretaceous		144–65 Ma	Extinction of the dinosaurs (at the end of this period)
				Matawai and Tinui Group rocks deposited in Gisborne District
				Rocks of the Northland and East Cape allochthons forming
				100–83 Ma: separation of Zealandia from Australia and Antarctica
				110 Ma: the boundary between basement and cover rocks
				Deposition of Pahau and Mt Camel terranes, the most recent basement terranes
	Jurassic		213–144 Ma	Deposition of Kaweka and, later, Pahau terranes (Torlesse composite terrane)
				Final stages in the deposition of Waipapa, Caples and Murihiku terranes
	Triassic		248–213 Ma	Majority of the Murihiku, Caples and Waipapa terranes deposited
Palaeozoic	Permian		286–248 Ma	Hunua-Bay of Islands (Waipapa) terrane deposition in Northland
				Dun Mountain-Maitai terrane deposited (to become the Junctional Magnetic Anomaly)
	Carboniferous		359–286 Ma	Earliest possible rocks in northern New Zealand (Purerua Peninsula, Bay of Islands)

Furthermore, the upper North Island has also started to stretch and rift apart. The southern apex of the rift is in the vicinity of Mt Ruapehu, and the two limbs of the North Island, Northland and East Cape, are being pushed ever further apart as one goes north. In the gap are two subsiding rift valleys, one in the TVZ and another in the Hauraki Plains, both of which are gradually filling with alluvium.

The plate boundary is not the only active geological feature. One of the greatest dangers to New Zealand's largest city, Auckland, is unrelated to the plate boundary. Auckland's volcanoes, as well as others in the North Auckland Peninsula, are 'intra-plate' volcanoes (discussed below), akin to the world's largest volcanoes in Hawaii.

Finally, ever since the end of the last glacial period, the sea level has been stable at approximately its current level and over that time headlands have been eroded and embayments filled in by flat plains to give us our present coastline. This process continues to operate today, with cliffs occasionally collapsing and new sandy lands, like those at Whatipu, arising within one 20th-century human lifetime.

THE BASEMENT ROCKS

New Zealand's islands are underlain by continental rock that, over millions of years, became attached to the side of the ancient southern continent of Gondwana, principally in the Mesozoic era (the western South Island and some parts of Northland were laid down earlier, in the Palaeozoic). Later, rifting would separate us and the other continents and subcontinents of the Southern Hemisphere from this giant supercontinent. Continental rock is lighter than oceanic rock because it has a higher silica content; this makes it more buoyant than both the oceanic crust and the mantle, such that blocks of it ride on the Earth's surface, poking above the sea level in the same way a rubber ducky floats in a bathtub. However, our continental crust is thinner than that of the major continents and as a result is less buoyant; hence most (about nine tenths) of the New Zealand subcontinent remains underwater. We term this large subcontinent, about half the size of Australia or the continental United States, 'Zealandia'.

ZEALANDIA IN THE MESOZOIC
CURRENT LANDMASSES SHADED
HEAVY LINES = BOUNDARIES OF ZEALANDIA

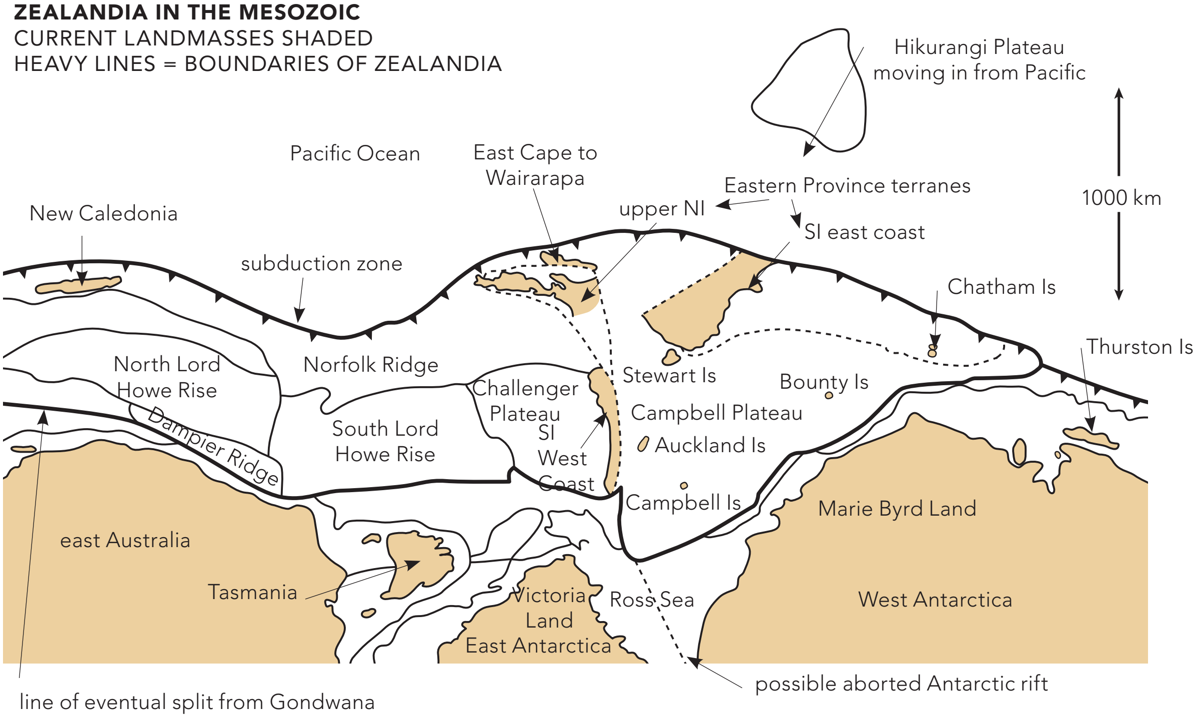


Figure 4 **Zealandia in the Mesozoic. Current landmasses are shaded and ocean blocks underlain by continental crust (i.e. continental shelf) are outlined. Note the large but thin continental landmass that would break away from Gondwana in the Cretaceous. Only small parts of this landmass are above sea level today, due to later submergence: most notably New Zealand and New Caledonia. Note also the different configuration of the western and eastern parts of New Zealand; movement on the Alpine Fault to bring them into their present alignment had not yet begun. The igneous, basaltic Hikurangi Plateau originated on the other side of the subduction zone, as did the rocks of the Northland Allochthon.**

The oldest and most stable parts of the seven continents on this planet are known as cratons and are billions of years old; Australia and Antarctica, to which Zealandia was adjacent when we were all part of Gondwana, both contain such cratons, in Western Australia and East Antarctica, respectively. New Zealand, conversely, does not contain a craton; rather, the underlying basement rocks comprise various 'terranes' that were gradually added to the side of Gondwana in a process known as accretion. Offshore from Gondwana there was a plate boundary, where the oceanic plate under the Mesozoic Pacific Ocean was being subducted under the edge of Gondwana's plate. Being denser and thus heavier than the continental rock, most of the oceanic slab descended into the depths of the Earth's mantle with the lighter sediments on its surface being scraped off onto the toe of the overriding plate. The movement of the oceanic plate towards Gondwana 'bulldozed'

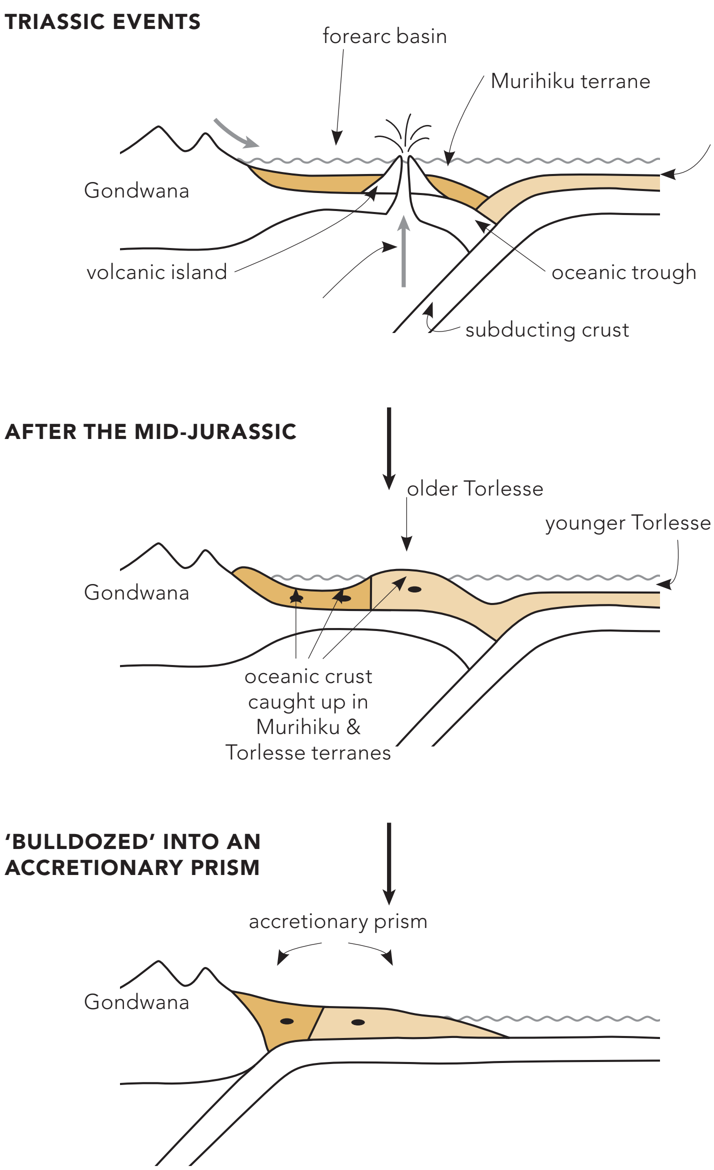


Figure 5 **A somewhat simplified schematic demonstrating the accretion of the Murihiku and Torlesse terranes to the side of Gondwana. The Murihiku terrane derives from sediment eroded from continental Gondwana as well as an offshore volcanic arc which ended up in a relatively stable basin; the Torlesse terrane, originally laid down as sediment on top of oceanic crust, was 'bulldozed' into it by the movement of the oceanic crust towards the subduction zone and then scraped off the subducting slab to form an 'accretionary prism'. This terrane therefore underwent much more compression and deformation than the Murihiku terrane, which remained closer to the original landmass and, with subsequent reconfiguration of New Zealand by the Alpine Fault, ended up on our western coast. There was a temporary pause in the mid-Jurassic, after which subduction continued and an accretionary prism built up. The particular part of Gondwana where these 'Eastern Province' terranes were accreted was not a craton, but instead was previously accreted rock which forms the 'Western Province' rocks of the western South Island; these rocks also lie at depth off our western seaboard.**

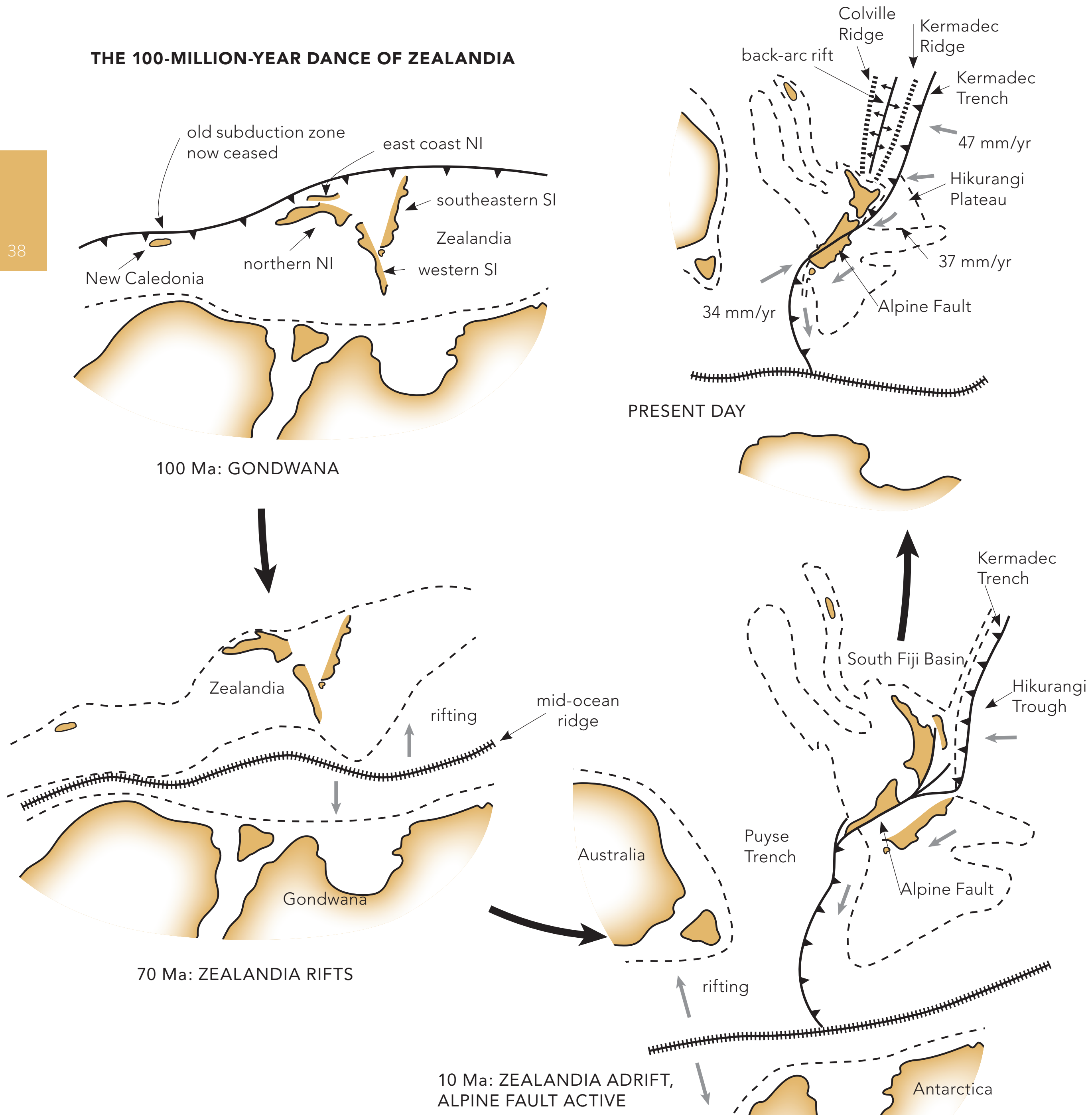


Figure 6 **New Zealand's original position off the coast of Antarctica and Australia and its subsequent movements. Initially a subduction zone is present off our coast. Activity ceases there and a rift develops, with sea-floor spreading, between New Zealand and Gondwana (Antarctica and Australia). After eventual separation, another subduction zone becomes active. Those parts of New Zealand on the Pacific Plate have moved south relative to those parts on the Indo-Australian Plate, separating the Murihiku basement rocks of Southland from its former neighbours under western Northland, Auckland and the Waikato. Back-arc rifting (see also Figs 15 and 20) begins behind the subducting plate boundary, with its southern terminus forming the Taupo Volcanic Zone.**

these sediments into the sediments being eroded down off the continent onto the other side of the subduction zone (as well as some volcanoes). The resultant wedge of material is known as an accretionary complex or prism and the process is termed accretion (Fig. 5). The parts of Gondwana closest to where Zealandia was accreted were, to our south, Marie Byrd Land (West Antarctica) and North Victoria Land (East Antarctica) and, to our west, eastern Australia, at that time still attached to Antarctica. These landmasses had themselves accreted to the cratons of Western Australia and East Antarctica earlier than Zealandia, but in a similar fashion.

Just prior to the end of the Mesozoic, activity ceased at this subduction zone and Zealandia rifted away from Antarctica and Australia. Possibly this was due to the igneous Hikurangi Plateau, at that time a relatively new, hot and buoyant mass, encountering the subduction zone and, being too buoyant to subduct, forcing this change. The thin crust of the Ross Sea region, with the active volcano of Mt Erebus, may represent an extension of this process between West and East Antarctica, but no oceanic crust was formed there; Marie Byrd Land did not manage to separate and head north, but remains part of Antarctica. In the future, it is quite possible that the spreading ocean ridge between us and West Antarctica will become inactive and we will slide back there again; equally, Marie Byrd Land may finally separate from the rest of Antarctica, coming to join us some day. Possibly we might split in two along the Alpine Fault, given that the southeastern parts of our country are on the Pacific Plate and heading south while the northwestern ones are on the Indo-Australian Plate. Possibly, also, the buoyant continental rocks of the eastern and southern South Island, the Chatham Rise and the Campbell Plateau might skip over the plate boundary, onto the Indo-Australian Plate, and all New Zealand might enjoy a gentle drift northwards into the tropics.

The first bit of our landmass that was formed, closest to the interior of Gondwana, was the Tuhua or Western Province rocks. These are not represented within the North Island but instead are out to sea off our western coast; our basement rocks are all part of the 'Eastern Province' which was formed during the next big land-building episode. Some of the terranes present in the north can be also found in New Caledonia, far to our north, and some (the Murihiku terrane) extend down to Slope Point, the southernmost tip of the South Island (but not Stewart Island).

GREYWACKE: OUR NATIONAL BASEMENT ROCK

The basement rocks in the north, and in New Zealand's Eastern Province in general — i.e. all of New Zealand except the South Island's West Coast and Otago — are dominated by what we know as greywackes, types of grey-coloured sandstone. The term 'greywacke' was abandoned in England as a rock name as

below **A typical greywacke landscape: the hills of northern Great Barrier Island, Auckland.**

right **Greywacke rocks (Pahau terrane) exposed on a beach, Opotiki District.**

opposite **A typical Northland hard greywacke headland — Tutukaka, Whangarei District, Hunua-Bay of Islands (Waipapa) terrane.**

early as the 19th century and it is not normally considered an official rock type, although it is very useful in the New Zealand context. Greywacke may also be used to refer to the very common admixture of this sandstone with argillite (hardened mudstone); there are often also small inclusions of chert, limestone and lava that have been either interbedded with or faulted into the greywacke. The particles that make up the sandstone are irregular and include quartz, feldspar and rock grains (lithic fragments), all stuck together in a muddy matrix to form a solid rock.

After their initial deposition, these rocks were buried at some depth and as a result were altered ('semi-metamorphosed'), making them harder (more indurated) than similar but later Tertiary rocks such as Waitemata Sandstone, which is how they may have appeared before this metamorphosis. The schist rocks present elsewhere in the country (particularly Central Otago), notable for their ability to be easily split into flat slices, are made up of the same sediments but were buried deeper in the Earth's crust, with more extreme pressure and heat, which caused their individual crystals to melt and re-form; hence they became changed into a completely different rock type and are a metamorphic rather than a sedimentary rock.

New Zealand's basement rocks are generally older than 110 Ma; the younger sediments which cover the greywackes tend to be much less deformed, well stratified (i.e. the layers of sediment within them are usually quite easy to see) and poorly indurated, because they have not undergone this same semi-metamorphosis. In places they may be 4 km or more thick.

Greywackes have several distinctive features, although not all greywackes are the same:

- they are hard, grey and made of layered, muddy sandstone
- the mineral and rock fragments that make them up, originally derived from granite, are cemented together with a fine clayey paste
- the fragment sizes range from fine silt to

pebbles, but are usually about the size of a grain of sand

- the fragments tend to become smaller as one goes vertically up the bed.

Greywacke country tends to be hilly with steep slopes. Classic examples of greywacke landforms in the north include the eastern bays of Northland, with sandy beaches separated by rocky headlands; the Hunua Ranges and western Waikato hills (although some of the latter are covered by later volcanoes such as Mounts Pirongia and Karioi); the gorges of the Raukumara Range, such as that carved out by the Motu River; and the rugged ranges of Te Urewera. Greywackes are also one of the main sources of aggregate for use on railways, roads and in construction because of their relative hardness, although many other rocks, usually those nearest to hand, have been used for these purposes (for instance, Auckland's basalts). Weathering of the basement rocks can produce kaolin and other clays, an important component of our soil and in the manufacture of pottery.

Greywacke basement rocks were emplaced over a period of 150 million years (see also Fig. 5); the process of their compression and distortion into an accretionary prism began around 250 Ma at the start of the Triassic Period, stopped temporarily in the Early Jurassic (at least from what we know from on-shore rocks; it may have still been happening elsewhere in the nine tenths of our continent that remain submerged), before beginning again in the Middle Jurassic and continuing into the Early Cretaceous. Compression of the basement rocks produced features still visible today, the most notable of which is perhaps the Kawhia Regional Syncline (a downward bowing of the rock; see below) visible in the Murihiku rocks of that area, but tilting and folding of the basement rocks occurred elsewhere also. As the greywackes were subject to tectonic pressure soon after their deposition, the stratification within them can usually only be traced a few kilometres before disappearing.

About 105 Ma, in the Cretaceous, the plate

margin stopped converging; subduction and accretion halted as a result and no further greywacke accumulated. The new piece of continental crust, our greywacke, then started to rise up because of buoyancy (isostatic adjustment); greywacke is relatively light compared with oceanic crust. The result of all this was the formation of a land called 'Zealandia' — the future New Zealand subcontinent, but for now a hilly country on the eastern edge of Gondwana.

right **Thin bedding is easily visible in this portion of greywacke (Hunua-Bay of Islands terrane). Other areas look much more homogeneous ('massive'). Long (Oneroa) Beach, Russell, Far North District.**

THE TERRANES OF NORTHERN NEW ZEALAND

Eastern Province rocks in the South Island, where they are clearly differentiated, have been divided, from southwest to northeast, into the Brook Street, Murihiku, Dun Mountain-Maitai, Caples, Rakaia and Pahau terranes, the last two being grouped together as the Torlesse rocks; the Rakaia is also known as the older and the Pahau as the younger Torlesse. The westernmost rocks on land in the upper North Island are the Murihiku rocks; there is only one outcrop of Dun Mountain-Maitai terrane on the surface (at Piopio), but it is identifiable at depth by the Junction Magnetic Anomaly (JMA). To the east of the JMA there is one small outcropping (in Northland) of a rock analogous to the Caples terrane, but the rest, the Waipapa, Kaweka and Pahau terranes, are geologically very similar to the Torlesse of the South Island and have been included, along with the Torlesse, in the so-called 'Torlesse Supergroup'. There are also small areas of schist and the 'mixed-up' Esk Head mélange.

Eastern Province rocks are younger than those of the Western Province. The earliest, in the Waipapa rocks of the far north, may possibly be Carboniferous in origin. They certainly date from the Permian, Triassic and Jurassic Periods, starting about 300 Ma; the Triassic has supplied most of New Zealand's basement rock.

MURIHIKU TERRANE

The name Murihiku comes from the Maori word for Southland, where these rocks are also very common — long ago Southland was adjacent to the western parts of the north, but the Alpine Fault which formed the Southern Alps has divided one from the other (Fig. 6). Murihiku rocks are more than 7 km thick and

MESOZOIC TERRANES OF ZEALANDIA: ORIGINAL POSITIONS

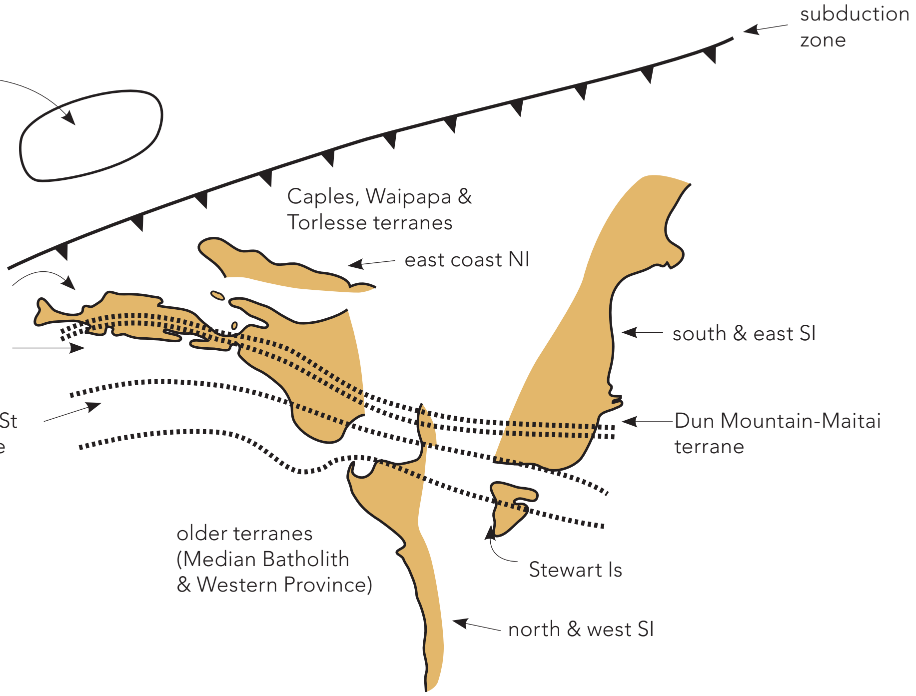


Figure 7 **Zealandia before separation from Gondwana. Note how the basement terranes were originally accreted in an orderly, regular sequence; both the North and the South Islands were in a different position in the Mesozoic and have subsequently been pulled apart by the Alpine Fault, distorting the original sequence (described under 'The Kaikoura Orogeny'). Note that the central North Island, containing older basement rocks, was accreted to the side of Gondwana before the Gisborne District. Hence it can be inferred that the Gisborne District was closer to the subduction zone.**

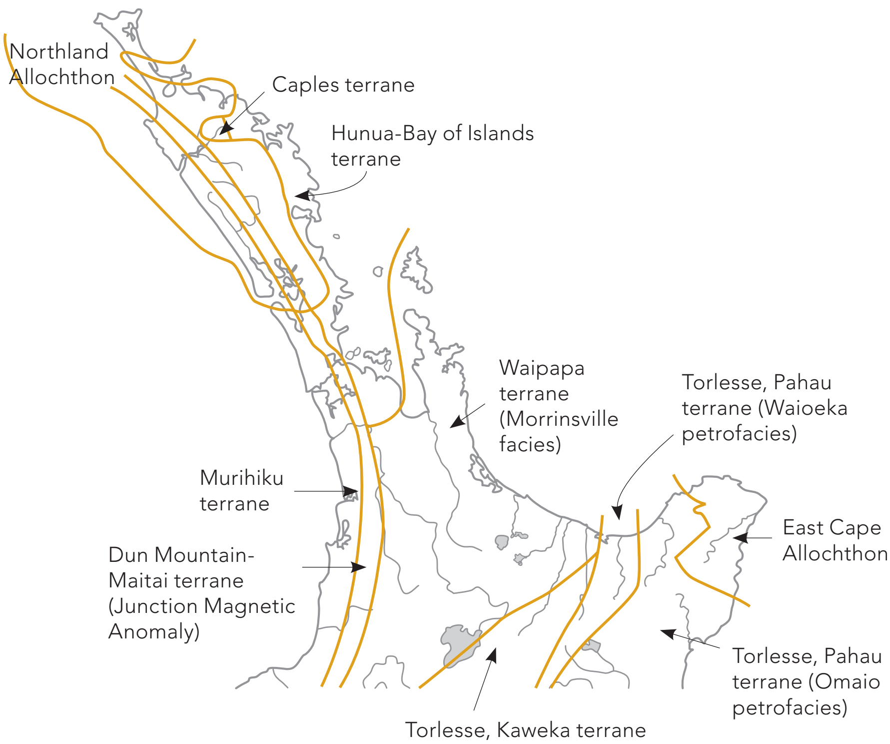


Figure 8 **The current position of the upper North Island's terranes.**

are made up of conglomerate, sandstone and siltstones, carbonaceous beds and volcanic tuff; they contain abundant fossils (are fossiliferous), because they were formed close to the shore, and volcanic debris. The rocks of the Murihiku terrane are predominantly greywackes, but have a different origin than those further east; they appear greener and are generally more volcanic (possibly they were derived, in part, from volcanic rocks of the median batholiths, now offshore to our west). They, along with the Brook Street and Maitai terranes (the 'Central Arc terranes'), seem to have escaped much of the subsequent changes that occurred to other rocks of a similar age, such as heating and metamorphosis, in the Cretaceous. The fossils within are therefore well preserved and the rock tends to have simple sedimentary layering, allowing productive study.

These rocks were partly formed from volcanic debris from an arc of volcanoes perhaps 1000 km long, erupting off the coast of ancient Gondwana (Fig. 5), between the aforementioned subduction zone and the approaching continent (this is known as a forearc basin). This volcanic arc may possibly have been part of the Median Batholith, a long volcanic belt now lying offshore to our west and older than the Eastern Province rocks; if this is the case, then the Murihiku sediments are only those deposited on the oceanic side of the arc. The ash mixed with sediment in shallow coastal waters to become limestone and sandstone, producing a type of greywacke rock. Rocks of this terrane, produced in the Triassic and Jurassic periods (248–142 Ma), are found at the surface in the west Waikato area as far north as Waikato Heads. Being relatively hard compared with more recent Tertiary cover rocks and Quaternary alluvium, they tend to form the erosion-resistant promontories of the west Waikato coast.

The youngest Murihiku rocks yet known

top **Marokopa Falls (Waitomo District). This 35-m-high waterfall is the result of the combined Mangapohue Stream and Marokopa River, having cut down through Te Kuiti limestone upstream of the falls, being held up by greywacke and in particular, at the lip of the falls, a hard Jurassic Murihiku mudstone and conglomerate bed. Downstream it has cut down through softer siltstones.**

bottom **The hills to the east of Raglan Harbour, merging into the Hakarimata Range, are of Murihiku terrane. The Hamilton Basin, with Hamilton City just visible as a white area, lies over the other side of these hills, in the right middle distance. Waikato District.**

have been found by drilling deep beneath western Northland, at Waimamaku near the Hokianga. Having been also found at depth under Grahams Beach in the Awhitu Peninsula, presumably they lie at depth all along our western coast, although they do not surface north of the Waikato.

THE KAWHIA REGIONAL SYNCLINE

Kawhia Harbour is formed from Murihiku rocks which, because of subsequent tectonic movements, are bowed downwards in the middle to form a syncline (Fig. 9) — a fold, typically downwards (a synformal syncline), with increasingly younger layers exposed as one goes towards the centre of the fold. Synclines can point upwards if they have been overturned and folded; folds bowed upwards in strata that have not been overturned are called anticlines. This same syncline is seen in the Murihiku rocks of Southland to which the Waikato rocks were once adjacent.

In fact, the situation is not quite as simple as that described above: within the large syncline there are smaller undulations, both synclines and anticlines. Given that it includes smaller folds, the proper term for the larger syncline should be 'synclinorium'. In places there are more recent sedimentary cover rocks and volcanic intrusions that obscure some of the detail, such as at the south head of Kawhia Harbour.

Such synclines are quite common in sedimentary rock; sediments are usually

below **Kawhia Harbour, Otorohanga and Waitomo districts. Older Triassic Murihiku basement rocks outcrop along the coastal (western) edge of the harbour (along with sand dunes on the left, the harbour's northern head) as well as in the distant hills beyond the harbour. The lowest point, i.e. the centre of the syncline, is located in the middle of the harbour, where younger Jurassic rocks are found on the surface.**

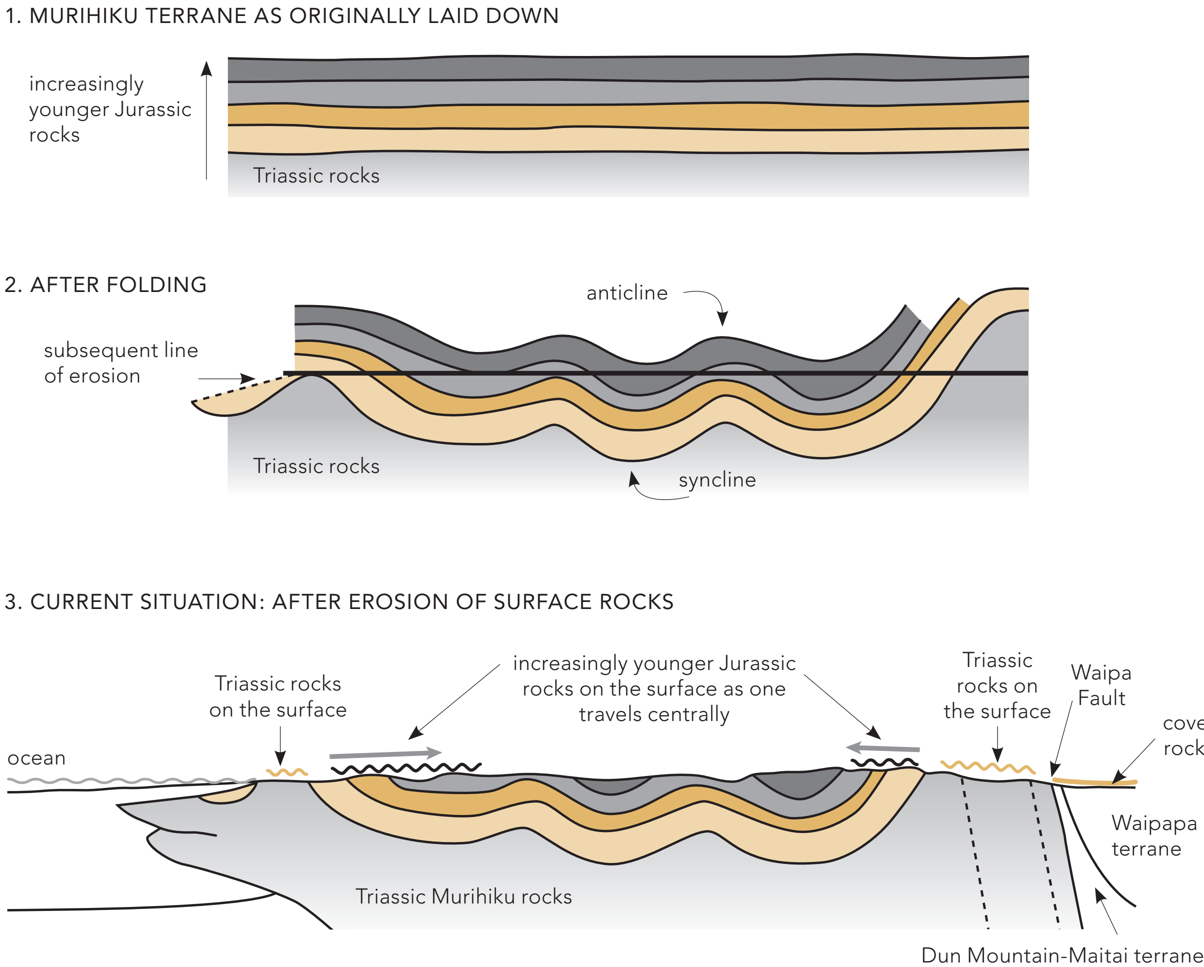


Figure 9 **The Kawhia Regional Syncline, just south of Kawhia Harbour, showing the Murihiku rocks as originally laid down (1), after folding into synclines and anticlines (2) and the current situation following erosion (3), showing how the older rocks are visible at the surface at the edges of the syncline, with younger rocks exposed more centrally**

laid down in horizontal layers (strata) as they are deposited on the sea floor, but are subsequently acted upon by tectonic processes, usually compression, so that they become folded like a concertina. The rocks in the dips (synclines) tend to survive longer than those at the apices (anticlines), being less subject to erosion both by virtue of being lower down (and hence less exposed to the agents of erosion) and because they are relatively compressed by the folding process — as opposed to the anticlines, which are stretched apart by the formation of the fold and are therefore more prone to fracturing.

At the midpoint of the syncline in the middle of the harbour, the older Triassic rocks are not visible but are instead buried under younger Jurassic rocks. To either side, at the raised edges of the syncline to east and west, the Jurassic rocks have been eroded away and the older Triassic rocks are exposed.

Kawhia Harbour is also perhaps the easiest place in northern New Zealand to observe Jurassic rocks and is rich in fossils from that time, including those of ammonites —

above **Fossil-rich rock (including ammonites of Late Triassic to Late Cretaceous age) in Murihiku terrane. Kawhia Harbour, Otorohanga District.**

prehistoric shellfish, some of which were huge. Fossils may also be found in similar Jurassic Murihiku rocks at Waikato Heads.

By the end of the Jurassic, the sea floor where the sediments that gave rise to the Murihiku terrane had been deposited had been pushed above sea level and became land; marine sedimentation thus ceased. There are, however, some non-marine Murihiku rocks, including Port Waikato's Huriwai Plant Beds from the Late Jurassic (which also contain a dinosaur fossil and one of our weta's ancestors).

THE TAUPIRI AND HAKARIMATA RIDGES

An interesting oddity, this range is made of a block of Murihiku terrane that has been moved sideways and rotated such that it now lies further east than is normal for this terrane; it sits on a bed of Waipapa terrane.

DUN MOUNTAIN-MAITAI TERRANE

At the eastern edge of the Murihiku rocks, running all the way from Northland to South Otago, is a band of ultramafic rock. Ultramafic rocks contain relatively large amounts of iron and magnesium; there is so much iron in this band that it produces a local alteration in the Earth's magnetic field, the Stoke's or Junction Magnetic Anomaly (JMA). Soil derived from ultramafic rocks typically produces stunted vegetation with a high degree of endemism compared with that in surrounding areas.

This band, the Dun Mountain-Maitai terrane, probably derives from a portion of Early Permian oceanic crust that got mixed up and attached to the Murihiku terrane, although exactly where everything came from is still a matter of debate and scientific study. The Dun Mountain-Maitai terrane was produced in the Permian Period (299–252 Ma); the most northerly surface outcrop of this terrane is at Piopio in the King Country, just outside the boundary of the upper North Island as defined in this text, where its blue-green serpentine rock is mined. One can also identify its presence further north, at depth, up as far as Ahipara Bay (where it then goes out to sea off the west coast) by the presence of the JMA; the Waipa Fault of the Waikato appears also to be a surface expression of this terrane. Ultramafic serpentines are also found in the Northland Allochthon, in particular

below **The Piopio mine, an exposure of Dun Mountain-Maitai terrane between the Murihiku and Waipapa terranes, near Te Kuiti, Waitomo District.**

at North Cape, but these are unrelated to this terrane (they are part of the Tangihua Complex Volcanics).

BASEMENT ROCKS EAST OF THE JUNCTION MAGNETIC ANOMALY: THE WAIPAPA, CAPLES AND TORLESSE TERRANES

These rocks probably formed from sediments deposited on an ocean floor; the plate beneath this ocean floor was then subducted under the plate carrying Gondwana. These sediments were scraped off onto the toe of the overriding plate, as previously mentioned (Fig. 5). Between the continent of Gondwana and the subduction zone, on the Gondwana Plate, was the area where the Murihiku terrane was being deposited, its volcanic arc being formed by the same subduction zone; hence, the two terranes have come to lie next to one another.

Terrestrial sediment was washed down from Gondwana, i.e. Australia and Antarctica, and accumulated on the ocean floor off its coast; along this coast were granites of the Median Batholith, which divides our older Western Province rocks from the younger ones of the Eastern Province. The New England Fold Belt of northeastern Australia has been identified as a possible sediment source of the Torlesse terrane; the source would appear to be a more northerly one than for the Murihiku terrane. Being accreted by the same subduction process forming the Murihiku terrane, these rocks accumulated over the same period, from 250 to 105 Ma.

The oceanic element in this terrane includes lava, ash and chert (from mid-ocean rifting and associated vulcanism), manganese nodules (which build up on ocean floors) and limestone (from shallower seas). The limestone fossils in the Pahau terrane of the Ikawhenua Range would appear to have originated a long way from the margin of Gondwana, in the Panthalassa Ocean. These oceanic sediments then became all mixed in with sandstone and mudstone from the continental shelf.

How did this mixing take place? We believe that terrestrial sediments washing out to sea initially accumulated in large piles on the continental shelf. Every so often these piles of sand and gravel collapsed, due to events such as storms or earthquakes, and were carried far out to the deep ocean in a kind of undersea landslide known as a turbidity current, down submarine canyons leading from the shelf to the deep ocean floor. One can see such fans of sediment accumulating at the bottom of submarine canyons today; the largest extend for 3000 km off the delta of the Indian subcontinent's Ganges and Brahmaputra rivers in the Bay of Bengal. The heavier, larger pebbles sank to the bottom first, with progressively smaller particles such as sand and silt coming to lie on top of the larger particles; the whole smothered the very fine particles of mud (silt) that had been gradually

below **A beach formed from erosion of Hunua-Bay of Islands (Waipapa) terrane; not just grey greywacke! Long (Oneroa) Beach, Russell, Far North District.**

accumulating on the floor of the previously quiet deep ocean, giving rise to the layering found in these rocks. Marine rocks such as chert, somewhat older because they were pre-existing, became mixed in at this time.

Because they mainly accumulated in deep oceanic water, although the younger rocks, dating after the Triassic, would appear to have been built up much closer to shore, these rocks are generally fossil-poor. However, east of Whangaroa in Northland, on the Arrow Rocks (Oruatemanu Island) and at Wherowhero Point between Marble and Orua bays on the mainland opposite, are some areas of limestone (mostly altered by compression into marble) formed by the shells of fusulinids, an extinct order of foraminifera dating from the Permian Period. The Arrow Rocks exposure also contains ocean-floor rocks such as chert, shale, mudstone and basalt as well as fossil radiolarians dating from both the Permian and the Triassic; hence, it extends from the Middle Permian to the Middle Triassic and forms one of the most complete sequences known of oceanic rocks spanning the Permian–Triassic boundary, when there was a massive worldwide extinction event.

The accumulated sediments were then carried by the underlying oceanic crust to the same subduction zone where the Murihiku rocks were forming (on the other side), eventually becoming part of an accretionary prism as described earlier. This process may have stopped or moved elsewhere in the Early Jurassic, starting up again later to form the younger rocks. Deformed and compressed by the 'bulldozer effect', some of the rocks were buried deeply enough that they became metamorphosed, forming the Haast schists, found mainly in Otago.

The Caples terrane (see below) probably formed adjacent to the Torlesse and eventually these terranes came to abut the Murihiku rocks which are, in northern New Zealand, to their west, with the Dun Mountain-Maitai terrane being a thin band between them.

The correct terminology for these greywacke rocks in our region is the subject of some debate. In the South Island, where they are clearly differentiated (having been subject to more uplift so that the cover rocks have been eroded away, as well as being much more free of recent volcanic overlay), the terranes east of the JMA have been divided, from southwest to northeast, into the Caples, Rakaia and Pahau terranes; the latter are included in the Torlesse composite terrane. Sometimes the Rakaia terrane is called the older Torlesse and the Pahau terrane the younger Torlesse, as the Rakaia dates from the Late Carboniferous to the Late Triassic and the Pahau from the Late Jurassic to the Early Cretaceous. In our area, the Kaweka terrane has only recently been differentiated from Rakaia; it has distinctive detrital zircon populations (zircon being a type of neosilicate mineral present in almost all rock types, often used to date rocks). It is also included in the Torlesse composite terrane.

For our northern rocks, the terminology is in a state of flux and more confused; how each type of rock relates to each other has been the subject of debate and change. The Torlesse and Caples terranes are certainly present; to them we add another, the Waipapa, which is certainly related and was probably formed adjacent to them. The term 'Torlesse Supergroup' has been applied to both the Torlesse terrane and the Waipapa composite terrane because of this, although it is not a term used by most authors.

WAIPAPA COMPOSITE TERRANE AND HUNUA-BAY OF ISLANDS TERRANE

From the JMA across to a line running from Taupo to the mouth of the Rangitaiki River, passing east of Kawerau, is a greywacke

top **A Waipapa composite terrane landscape, looking across from the historic town of Russell to the equally historic Paihia. Bay of Islands, Far North District.**

bottom **A Waipapa (Hunua-Bay of Islands terrane) outcrop at Administration Bay, Motutapu Island, Auckland. Note the deformation and fracturing within the thin-bedded chert and siliceous argillite in this area, within a graded sequence of sandstone and argillite.**

basement rock that tends, at least in parts, to be more volcaniclastic and less quartzofeldspathic than the Torlesse (i.e. it has more chunks of volcanic rock and less of quartz and feldspar minerals); as a result it tends to be darker and muddier. Within this large band of greywacke are patches of other types of rocks, such as red volcanic rocks with deposits of copper on Kawau Island and manganese on Kawau, in Northland and in the Hunua Ranges. This greywacke is often mapped as the Waipapa composite terrane. The term 'composite' means that it consists of multiple fault-bounded units with different geological histories.

The debate surrounding the correct terminology for this terrane has given rise to a confusing and changing nomenclature. It was initially described as having three different facies (i.e. three different rock types); however, one — the Omahuta — has now been recognised as being analogous to the Caples terrane of Otago (see below). The other two facies are often termed the Hunua and Morrinsville facies; the latter is also called the Manaia Hill Group. Debate still surrounds even these two remaining terms, and some would consider the northern part of it, the Hunua facies, as a separate terrane. Hence this northern part of the Waipapa composite terrane is also known as the Bay of Islands terrane or the Hunua-Bay of Islands terrane.

Although both dominated by volcaniclastic sandstones and argillite (i.e. greywacke which includes significant volcanic debris), the Hunua and Morrinsville facies differ in some respects. The Hunua Range comprises mainly sandstones with inclusions of chert and basalt (known as tectonically intercalated material), whereas the Morrinsville facies contains larger-grained sandstone and conglomerate particles and tends to be coarser. The Morrinsville facies has also been subject to less deformation and metamorphosis.

As with the other greywackes, it is thought that the Waipapa terrane derives from ocean-floor material that became tectonically intercalated with clastic sedimentary rock in an accretionary prism at the edge of Gondwana in Permian to Jurassic times;

it tends to become younger as one goes south. Hence, although north of Whangarei Permian and Triassic fossils are present (e.g. the aforementioned Arrow Rocks), further south the rocks date from the Triassic to the Jurassic. At Purerua Peninsula in the Bay of Islands there is a possible Carboniferous fossil, the oldest fossil and rock (if verified) in the North Island.

The Waipapa and Kaweka terranes, although formed in different places, came together around the end of the Jurassic and beginning of the Cretaceous (160–140 Ma) and were followed by the formation of the Pahau.

CAPLES TERRANE

In New Zealand as a whole, east of the main Permian ultramafic belt (the Dun Mountain-Maitai terrane) is a thick deposit called the Caples terrane, of Triassic age. The term derives from a South Island river which drains into Lake Wakatipu. It is quite extensive in Southland and Otago, but there is an area of rock (the uplifted massif on which the Omahuta and Puketi forests grow) analogous in position to this terrane in Northland, northeast of the Hokianga Harbour. Given its location and geological similarities it is also thought to be Caples terrane, laid down in the Triassic.

This terrane is predominantly composed of layers of sand and mud which were deposited in deeper water with few shellfish (and therefore short on fossils), at the same time as the Murihiku terrane. The Caples was probably deposited together with the Torlesse and Waipapa terranes off the coast of Gondwana; it was probably the most

below **Caples terrane; erosion-resistant and therefore protruding above the level of the surrounding landmass, cloaked in the Puketi Forest, Far North District.**

right **Kaweka terrane exposed in a road cutting on the Napier–Taupo Road. Note how homogeneous ('massive') it is. Taupo District.**

southerly, as the few fossils in it are generally those associated with a colder climate. The resultant rock is predominantly greywacke, i.e. sandstone and argillite, but one may also find areas of chert, volcanic tuff and basalt, the latter most likely from undersea volcanoes (e.g. guyots, flat-topped volcanic seamounts which once protruded above the waves but have since sunk).

TORLESSE COMPOSITE TERRANE

To the south and east of the Waipapa terrane are basement rocks of the Torlesse composite terrane — composite because once again it is a mixture of different subterranes. It is named after a mountain range in Canterbury — another South Island name for North Island basement rocks! The boundary between the Waipapa and Torlesse terranes lies buried under the very recent volcanic rocks of the TVZ, but it approximates the line joining Taupo to the mouth of the Rangitaiki River.

Kaweka terrane

The Kaweka terrane is found to the southeast of the Waipapa, reaching only as far north as the Waihou Basin rather than all the way to the eastern Bay of Plenty coastline but extending into Marlborough in the South Island. The Kaweka terrane is exposed in the Kaimanawa Range and in outcrops on the Kaingaroa Plateau, and is the main rock type of the hills of the western part of both Te Urewera and the Whirinaki Forest Park.

The Kaweka terrane is rich in quartz and feldspar and, at least in the north, is of Middle to Late Jurassic age. It is dominated by massive, fine-grained quartzofeldspathic sandstone with minor alternations of sandstone and mudstone. Along with the Waipapa terrane, which lies between it and the Bay of Plenty coast, it is separated from the next terrane over, the Pahau, by the Whakatane mélange, which is visible in the rocky coastline east of Whakatane and extending south through Te Urewera, passing west of Ruatahuna. This mélange, a type of rock typical of accretionary prisms, consists of broken, fragmented and mixed-up rocks of all different sizes and includes slices from

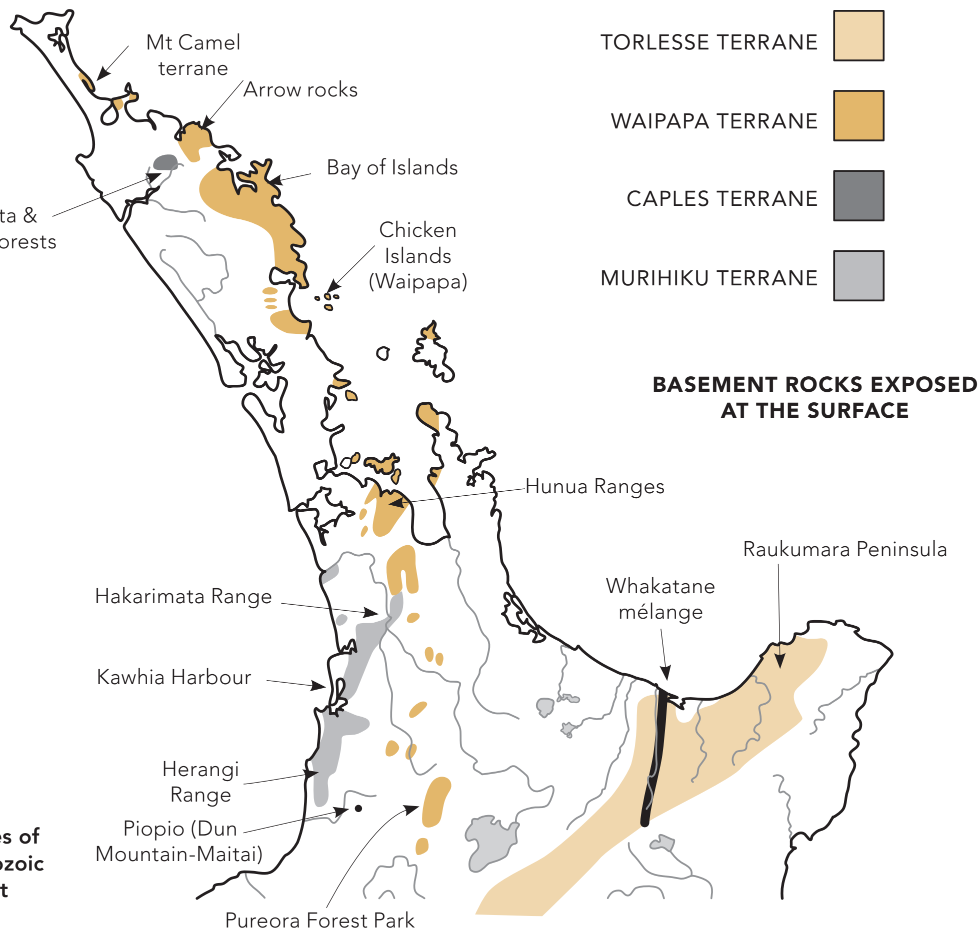


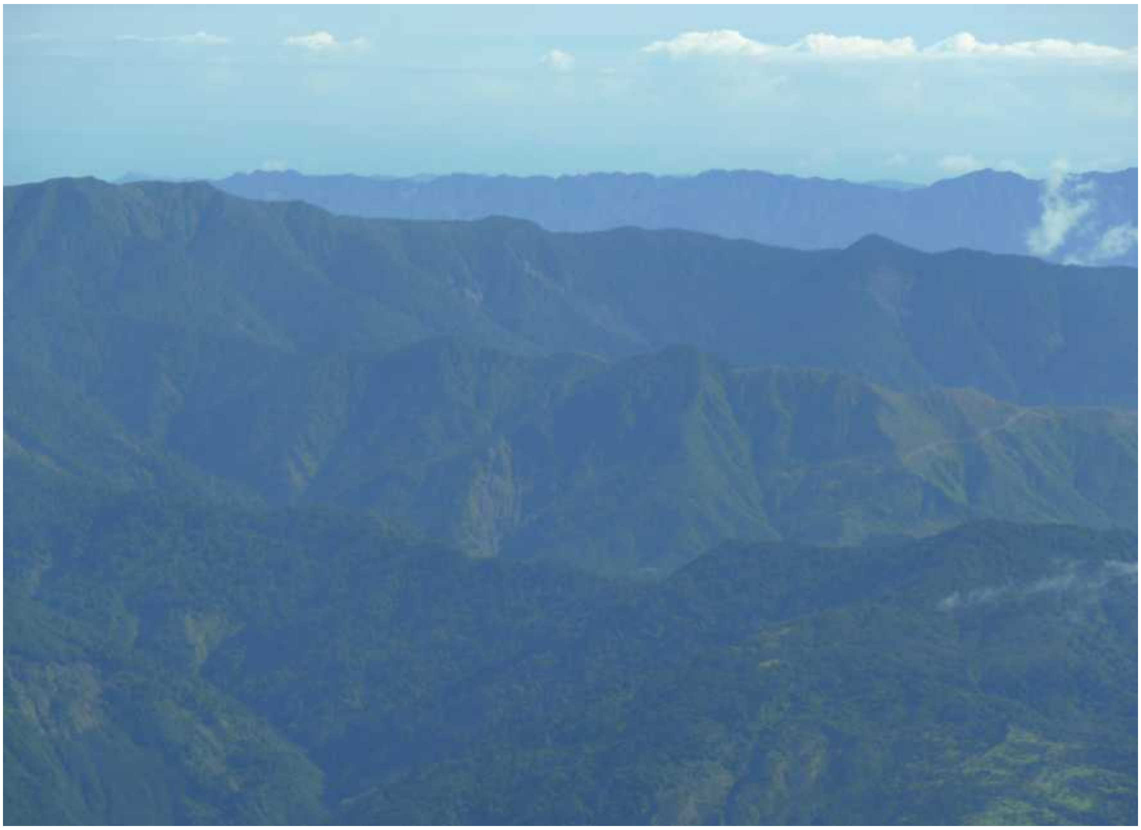
Figure 10
Surface exposures of the Mesozoic basement terranes.

both neighbouring terranes together with conglomerates, cherts and limestones.

Pahau terrane

The Pahau, or younger Torlesse, though still greywacke, contains more recycled sediment and volcanic debris and is of Late Jurassic and Early Cretaceous age. It consists of alternate, graded beds of sandstone and siltstone, each bed being centimetres to tens of centimetres (decimetres) thick. The term 'graded' means that the particles gradually get smaller as one traverses each particular bed, rather than having different-sized particles mixed up throughout. There is also some pebbly mudstone to conglomerate present.

The more easterly part of the Pahau terrane, underlying the eastern Bay of Plenty and the Gisborne District, is often termed the Waioeka petrofacies; the Waioeka is exposed on the surface in the northern slopes of the Raukumara Range and in Te Urewera east of Ruatahuna, almost as far as south Lake Waikaremoana. The Waioeka petrofacies contains bits of volcanic rock (i.e. has a volcaniclastic element), unlike the rest of the Pahau, which is termed the Omaio petrofacies. Some authors have elevated the Waioeka to full terrane status, as part of the Torlesse composite terrane, while others believe that they are not separate terranes or subterranes as they lack a faulted contact. The Pahau



above **The axial ranges; here the Raukumara Range. The Waioeka petrofacies forms the crests of the ranges with Cretaceous Matawai Group rocks in the foreground. Gisborne District.**

is of Early Cretaceous and maybe in part Late Jurassic age and is overlain by other sedimentary rocks such as the Matawai Group which date from both the Early and the Late Cretaceous, although whether there is a clear distinction between the two is debatable.

WAIPA SUPERGROUP

One will often see the Manaia Hill Group and the Torlesse rocks of the north mapped as the Waipa Supergroup. This name was given to these rocks as they are all covered by a similar, more recent (but still older than 110 Ma) volcaniclastic blanket derived from the Median Batholith (offshore to our west) in the Late Jurassic and Early Cretaceous. It also includes the very superficial rocks overlying some of the Murihiku rock west of the JMA.

MT CAMEL TERRANE

The Mt Camel terrane is a small terrane with its own distinctive characteristics. It is found in the far north, at Mt Camel (east of Houhora Harbour), the Karikari Peninsula, Rarawa-Henderson Point and The Bluff (on Ninety Mile Beach), and it also is found at the Three Kings Islands. It is rich in volcanic debris as well as sandstone and mudstone, dates from the Early Cretaceous and is New Zealand's youngest Mesozoic basement terrane with no known correlate elsewhere in New Zealand, although there are similar rocks in New Caledonia. It is the only terrestrial exposure of the submerged sedimentary basin and volcanic arc that are major features of the submarine crust to our north.

THE RANGITATA OROGENY AND THE CREATION OF ZEALANDIA

It is often written that sediment is eroded off surrounding land and gradually deposited in various layers on the ocean floor before being pushed up in an orogeny (a mountain-building episode) to become land, after which the land subsides and erodes away again so that sedimentation begins anew and the cycle continues. Hence, the accumulation, folding and uplift of the Eastern Province basement rocks is often referred to as the Rangitata Orogeny. In reality, the process of accretion is more complicated: both sedimentation and uplift occur concurrently, as do erosion and subsidence.

Nevertheless, by the Middle to Late Jurassic much of Zealandia was above the water (subaerial). Around this time it is likely that some new plant and animal groups migrated here from elsewhere in Gondwana, including the podocarps, araucarian pines (ancestors of kauri), the ancestors of our native frogs, tuatara, peripatus (one of our smaller 'living fossils') and the ancestors of insects such as the weta.

By the Cretaceous, most of Zealandia was above sea level and hence little sediment was laid down. Instead, the basement rocks, being now subaerial, started to become eroded by the elements to form an ancient surface that, in a few places, can still be seen, including along part of the coastline of Motutapu and Waiheke islands, where the younger sediments that used to cover it have since been eroded away. Exceptions include the basaltic eruptions that make up the Tangihua Range in Northland and the Matakaoa volcanics south and west of Hicks Bay (near East Cape, at that time contiguous with Northland) and continuing marine sedimentation in the east, since the area of the Raukumara Range was still underwater. These marine sediments formed the Pahau terrane and the Matawai Group; the latter (see below) only just postdates the Pahau; one almost merges into the other with the hard greywacke becoming softer with increasing youth. The stages of deposition of the sandstone and conglomerate can be seen particularly in the Motu Falls area and at Orete Point near East Cape; at the latter site the rocks have been overthrust (an allochthon, described below) so that older rocks sit on top of younger ones.

below **An ancient and modern coastline at Home Bay on Motutapu Island (near Auckland). The rocks in the foreground are composed of Hunua-Bay of Islands greywacke, once covered by Waitemata rocks but since exhumed to form the modern coast.**

IMMERSION: THE COVER ROCKS

The Cretaceous Period represents the final years of the Mesozoic Era, the age of dinosaurs that lasted up to 65 Ma. After this, one enters the current Cenozoic Era, the age of mammals (at least, outside New Zealand). The divisions within it are many, multiple and perhaps confusing (see Fig. 3). Those used currently are the Palaeogene (older than 23 Ma), Neogene (from 23 to 2.588 Ma) and Quaternary (2.588 Ma to the present) periods. The Palaeogene may be further subdivided into the Palaeocene (65–55 Ma), Eocene (55–34 Ma) and Oligocene (34–23 Ma) epochs; the Neogene into the Miocene (23–5 Ma) and Pliocene epochs (5–2.588 Ma); and the Quaternary into the Pleistocene and Holocene (see below). The older term 'Tertiary', still often used, denoted the time period from 65 to 1.806 Ma, i.e. including the Palaeogene, the Neogene and part of the Pleistocene (the first part of the Quaternary, which prior to 2009 was considered to start at 1.806 Ma).

We term the rocks that formed after about 110 Ma cover rocks, to distinguish them from the older basement rocks that had been deformed and mildly metamorphosed by the tectonic events involved in their creation. These rocks 'uncomfortably' overlie the basement rocks, i.e. there is an obvious break between the two series, except perhaps in the east, east of the Moutohora Fault in the Gisborne District, where some argue for a gradual transition from one to the other. The cover rocks were mostly laid down during a long period of subsidence as Zealandia rifted away from eastern Gondwana, now represented by Australia and Antarctica. This process started about 100 Ma, with final separation occurring during the Cretaceous, about 83 Ma; Australia and Antarctica also rifted apart at approximately the same time, probably achieving complete separation slightly sooner than New Zealand's final separation with West Antarctica. New Caledonia was under the sea until the Late Eocene when it was uplifted and became land, but land connections between it and New Zealand were lost with the opening of the South Fiji Basin at around the same time.

The Tasman Sea gradually widened until

left **South of Omaio, on the eastern Bay of Plenty coast, an unconformity is present between Waioeka rocks (Pahau terrane) below and Quaternary colluvium and tephra above. (Colluvium refers to sediment deposited at the bottom of a slope, having been transported there by gravity, as opposed to the very similar alluvium, which is sediment that has been transported by water.) Opotiki District.**

sea-floor spreading there stopped 53 Ma, in the Early Eocene. As Zealandia moved away from the thermal rift separating us from Gondwana, our piece of crust lost support from mantle convection, cooled and stretched (and so became less buoyant); bereft of the support of the rest of Gondwana, we started to sink.

Later, between about 40 and 23 Ma, north of Zealandia the Indo-Australian and Pacific plates were converging (with the Pacific Plate subducting under the Indo-Australian), while south of Zealandia they were diverging. Although there was therefore tectonic activity around us in this period, Zealandia — being in the middle of the 'pivot' — experienced very little stretching or compression and, being tectonically quiet, continued to sink. We reached our maximum submergence about 23 Ma, after a period of 60 million years and having sunk about 2–3 km.

As Zealandia moved apart from Gondwana the crust stretched, causing faults running in a roughly north–south orientation in our area (e.g. the aforementioned Waipa Fault at the eastern edge of the Murihiku rocks, marking the JMA) as well as a few faults trending east-northeast which are probably transfer faults, such as the Marokopa Fault.

As a result of submergence, from the Late Cretaceous to the Early Miocene sediment accumulated in an increasingly marine environment. These sediments are particularly prominent in Northland, the Waikato, the Raukumura Range and the Gisborne District; the eastern part of our region had already become flooded in the Cretaceous and, in the Tertiary, the western part also began to sink. Sediment from the eroding hills accumulated in large submarine basins on top of the Murihiku basement rocks to create the Te Kuiti and later groups of rocks.

At maximal submergence (also known as the MMI, or maximal marine inundation), there is some debate over whether any of New Zealand was above water. Possibly in northern New Zealand there could have been some small islands north of Northland as well as perhaps the Herangi Range in the southwest Waikato, but we know that at least the vast majority of New Zealand must have been underwater as limestone was deposited all over the country over a period of about 10 million years, from the Late Oligocene to the Early Miocene. Because limestone is formed from marine organisms and dissolved oceanic calcium carbonate with little terrestrial sediment carried down to the sea by erosion, there must have been little if any land in the vicinity.

above **Fossiliferous limestone, Waitomo District — with oyster shells still visible!**

From 23 Ma (in the Miocene) we began to rise again, but the vast majority of Miocene rocks are still marine (there are some Miocene lignites in the Waikato); they can be found particularly in Auckland, the Waipoua Forest region of the far north, southwest Waikato, East Cape/Raukumara and the Huiarau Range.

While we were drifting and sinking, a cataclysmic event marked the end of the Cretaceous Period of the Mesozoic era: 65 Ma the Chicxulub meteorite struck our planet where modern Mexico is, giving rise to a thin

band of the otherwise rare element iridium, present in multiple locations worldwide although not visible in northern New Zealand. This explosive collision caused the extinction of the greatest land beasts ever to have existed, the dinosaurs. This geological event gave, in most parts of the world, a chance for mammals to enter centre stage; not, however, in New Zealand, which had already separated from the other continents, although we have bats which presumably flew here and marine mammals which have swum here. Instead birds, the last descendants of the dinosaurs, took over.

TE KUITI GROUP ROCKS

Between the mainly greywacke (Murihiku) hills of the coastal west Waikato and the similarly greywacke-based (Waipapa) ridges separating the Lower Waikato from the Hauraki Plains and Lake Taupo is a low-lying land filled with young sediments, the surface rocks of which tend to become younger as we travel further north and east away from the King Country and west Waikato hills and into the Hamilton and Lower Waikato basins; Oligocene limestone of similar age can also be found covering the northern parts of the western hills, from Raglan Harbour to Port Waikato, together with some volcanoes. The earliest of these sediments, those deposited during the subsidence of Zealandia in the Early Tertiary Period up to the Early Miocene, are known as the Te Kuiti Group.

below **Limestone of the Te Kuiti Group, showing prominent fluting. Hikurangi, Whangarei District.**

TE KUITI ROCKS: A MARINE TRANSGRESSIVE SEQUENCE

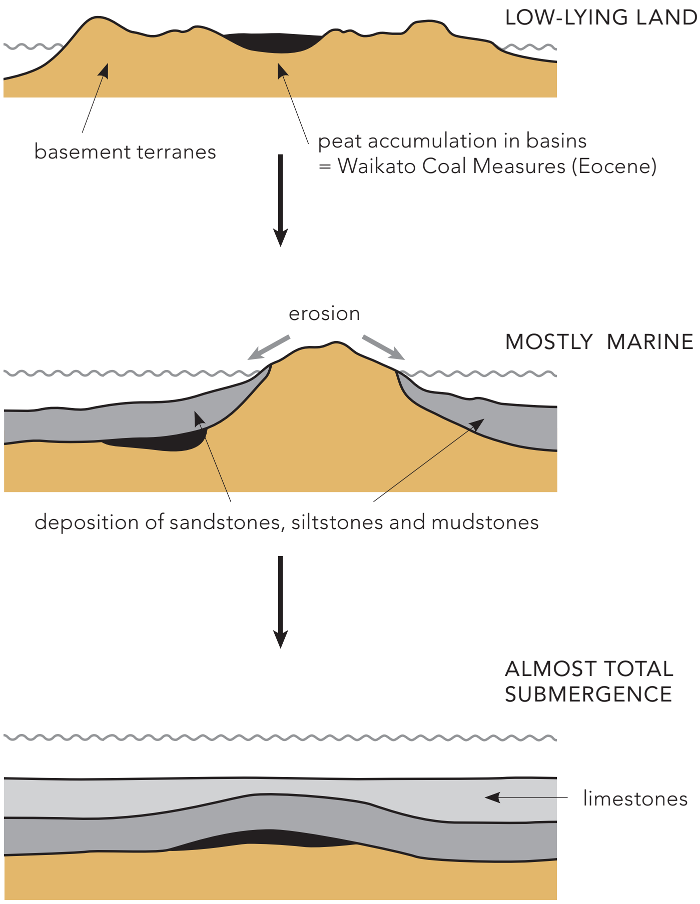


Figure 11 **The formation of the Te Kuiti Group, showing how the different types of rocks accumulated in a marine transgressive sequence as the sea gradually covered the land. The oldest, the terrestrial coal measures, are on the bottom, and on the top is marine limestone.**

These Te Kuiti Group rocks are about 500 m thick in the northern Waikato, thinning to the south, and are also present, at depth, under Auckland and even under Kaeo in the Far North District.

This group is a classic ‘marine transgressive sequence’, where the character of each successive layer of rock indicates that it was deposited in a marine environment that was becoming increasingly deeper with time. The coal that was laid down first was derived from deposits on land, i.e. peat in freshwater bogs. The next sequence of sandstones, siltstones and mudstones was deposited at sea, but not too far from land — as these sediments have a terrestrial origin. In general, the relatively larger particles that comprise sandstone are laid down much closer to a coast than fine silt particles, as the heavier particles tend to fall to the ocean floor much more quickly than smaller ones; silt can, however, be deposited close to shore if the water is very still, as for instance in our present-day west coast harbours. The final group, the limestones, were deposited in a marine environment that must have had very little land around it, given the absence of land-derived sediments. This is the limestone, with analogues throughout New Zealand, that provides evidence as to the paucity of land in

our region at the maximal marine inundation 23 Ma. Not all layers are represented in all areas and others are thicker in some locations than others.

The Eocene Waikato Coal Measures are the earliest of the Te Kuiti rocks, derived from the peaty swamps that formed as the land subsided following the end of the Rangitata Orogeny; now an important economic resource, they stretch right across the Waikato from Te Kuiti to Maramarua as well as west to Kawhia.

The next in the Waikato sequence of this group, the first to be deposited in a marine environment, are the Whaingaroa Siltstones which are visible at Raglan (Whaingaroa). These are followed in turn by the Aotea Sandstones (with siltstones and mudstones being more dominant north of Pirongia and sandstones more dominant further south). At Kawhia, Aotea Sandstones can be seen lying on top of darker Jurassic Murihiku sandstones; the sediment beds of the latter are tilted at a different angle to those of the Aotea Sandstones, due to tectonic movement of the older Murihiku sandstones before deposition of the cover rock. We refer to this feature of younger rocks sitting on much older rocks, with the once-horizontal sediment layers of the latter often tilted at a different angle due to tectonic movements occurring before the younger rocks existed, as an 'unconformity' or an 'unconformable' overlap. Such an unconformity, indicating that almost immeasurably long time must have passed between the two layers being laid down, was observed by James Hutton, the 'father of geology', in similar rocks in Scotland, and was one of the first clues to the truly immense age of the Earth.

Seen more prominently in the south and west Waikato, these layers were then overlain with the youngest rocks of this sequence, the shell beds that became Otorohanga (and Orahiri) Limestone and which have formed our famous Waitomo Caves. The limestone in these caves is being gradually worn away by the water flowing through them, not only by mechanical means but also from chemical dissolution of the limestone into carbonic acid, and hence the huge caves have opened up over a relatively short time; faulting due to our active geology has also been a factor in allowing water to gain access in the first place.

NORTHLAND AND EAST CAPE ALLOCHTHONS: THE JUMBLED-UP ROCKS

In Northland, as in the Waikato, the basement Murihiku and Waipapa terranes are overlain by the coal measures and sediments of the Te Kuiti Group. Te Kuiti Group rocks in Northland have different names from those in the Waikato but conform to the same basic pattern of a marine transgressive sequence, starting with the Eocene Kamo Coal Measures which are overlain by or intercalated with Ruatangata Sandstone, followed by, in the north, Mangapu Mudstone, which dates from the Late Eocene and Early Oligocene. The youngest in the marine transgressive sequence, Whangarei Limestone, dates from the Oligocene. Once again, not all layers exist in all places — for instance, in some locations, Mangapu Mudstone or Whangarei Limestone lies unconformably on basement rock.

These Te Kuiti Group rocks are in their original positions; however, in the submarine Northland of Early Miocene times (starting at about 24 Ma in the far north and around 21 Ma in the southern part of Northland), other sedimentary and volcanic layers of Cretaceous to Early Miocene age to the east slipped off the top of their basement rocks, slid westwards 150–200 km and came to lie on the western side of the pre-exising Te Kuiti and older rocks. This slide was probably a result of the onset of subduction in the now active plate

FORMATION OF THE NORTHLAND AND EAST CAPE ALLOCHTHONS

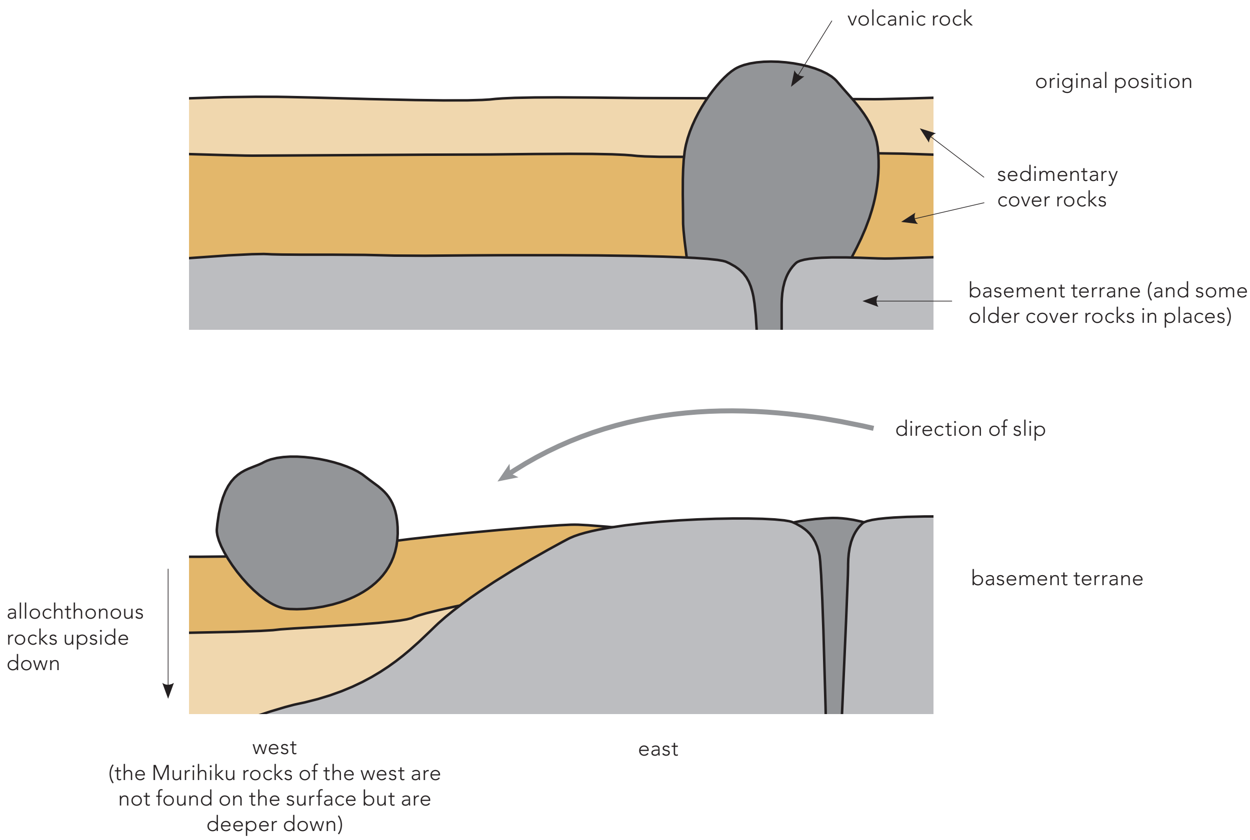


Figure 12 **Formation of the Northland and East Cape allochthons. Warping of the Earth's crust led to huge blocks of both sediment and volcanic rocks sliding off one part of the ocean floor and ending up, upside down in a jumbled-up pile, 150–200 km away. In eastern Northland, the basement rocks are now exposed.**

boundary to our west, which commenced around that time.

These rocks ended up in a jumbled-up, disorganised pile up to about 4 km thick. The term for rocks that are not in the same position as they were originally deposited is 'allochthonous' and such a slide, where oceanic crust is thrust over continental crust, is known as obduction (the opposite of subduction). In places the allochthonous rocks intercalate with Te Kuiti and Waitemata Group rocks and, very unusually, sometimes older Cretaceous rocks can be found on top of the younger Oligocene limestones and coal measures. This jumble, the Northland Allochthon, is relatively unstable compared with the harder basement rocks elsewhere and landslides are thus a significant geological hazard in Northland.

Another obduction, unrelated to the Northland Allochthon, occurred in New Caledonia and it is no coincidence that around this time (in fact, slightly earlier, in the Late Eocene) the South Fiji Basin began to open to our north, severing our land connection with that landmass. Rifting and tearing was beginning on a major scale throughout the whole region.

left **The flat surface of the Ahipara massif, south of Kaitaia, Far North District.**

It is also no coincidence that at the far eastern edge of our area, in East Cape, there is also an allochthon; indeed, it is the very same allochthon, as this area and Northland were once contiguous but have since become separated. The East Cape Allochthon therefore has rocks analogous to those in Northland and contains rocks of similar Cretaceous to Oligocene age.

VOLCANIC ALLOCHTHONOUS ROCKS

The volcanic rocks within the allochthon, which date from the Late Cretaceous to about 50 Ma, contain mainly tholeiitic basalt, breccia and tuff, deriving from mid-ocean ridge lava; they are intruded by subvolcanic basalt, dolerite, diorite and gabbro, as well as mudstone (and rarely limestone) that became intercalated with the volcanic rocks. In the Ahipara and Whangape massifs there are also alkaline basalts, typical of oceanic islands. Termed Tangihua Complex rocks, they are generally harder than the sedimentary rocks surrounding them and hence stick out as fault-bounded masses to form some of the highest hills of western Northland, including the Tangihua and Maungaru ranges as well as the Reinga, Maungataniwha, Ahipara, Warawara, Mangakahia and other, smaller, massifs; analogous to these in the Gisborne District are the Matakaoa volcanics, which form the Matakaoa and Pukeamaru massifs encircling Hicks Bay. The summits of many of the massifs (e.g. Ahipara, Whangape, Waima and Warawara) are quite flat, having been shorn by marine erosion some time after the Northland Allochthon became emplaced but before the Early Miocene volcanics erupted. These Early Miocene volcanics overlie the Tangihua Complex south of the Waima Range; the western part of the Waipoua Forest rests on a plateau formed from the Miocene Waipoua volcano rather than Tangihua Complex. At North Cape, the Tangihua Group includes plutonics (volcanic rocks that solidified while still underground) with serpentised peridotite, an ultramafic, overlain by gabbro which itself contains later

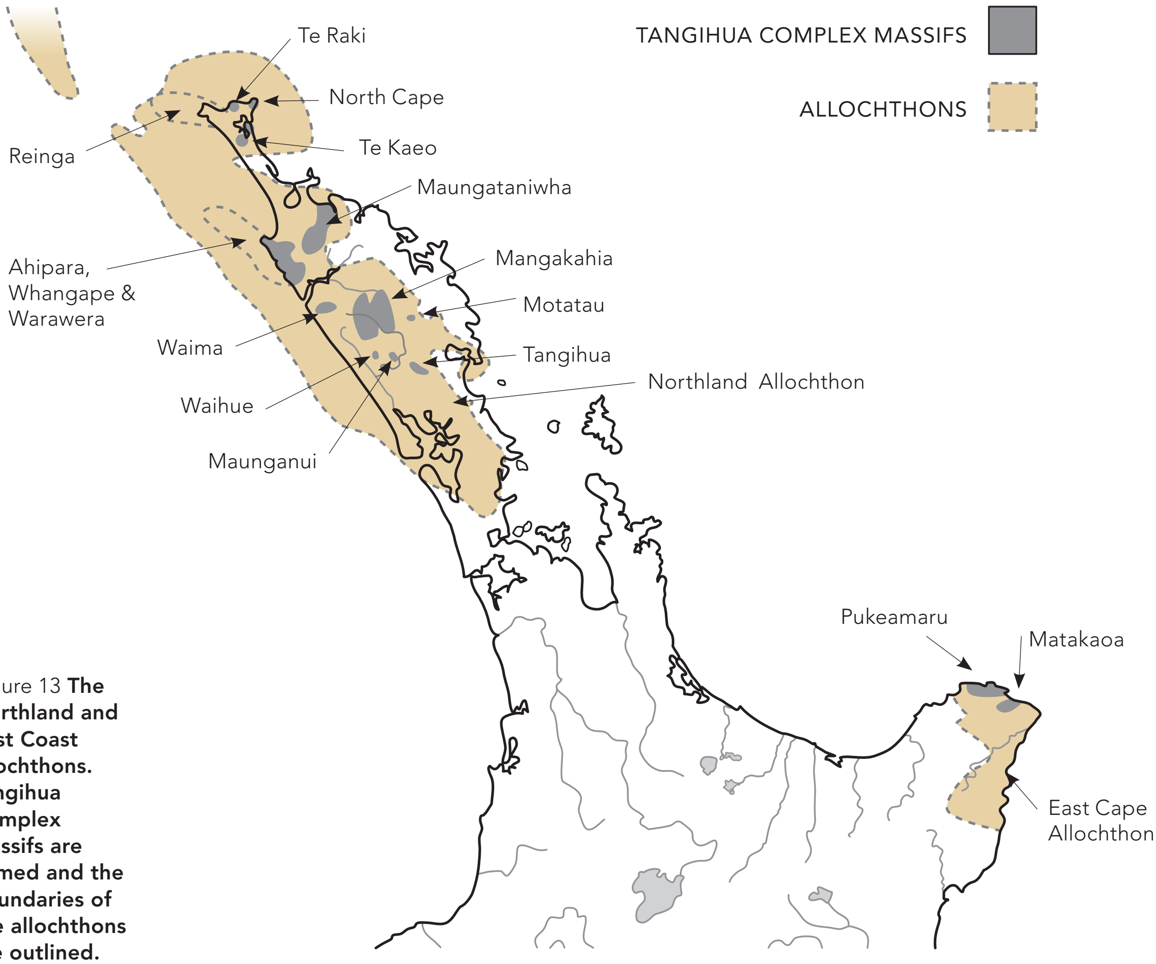


Figure 13 **The Northland and East Coast allochthons. Tangihua Complex massifs are named and the boundaries of the allochthons are outlined.**

horizontal intrusions (sills) of microgabbro and microdiorite. A distinctive plant community has developed on these rocks.

The origin of the Tangihua and Matakaoa volcanics may be the Hikurangi Plateau, a thick igneous plateau of Early Cretaceous age in the ocean to our east, which originally lay on the other side of the Mesozoic subduction zone from the accreting Zealandia and eventually collided with the New Zealand continent in the Early Miocene.

SEDIMENTARY ALLOCHTHONOUS ROCKS

The sedimentary component of the allochthon consists mostly of rocks of the Mangakahia Complex, with some Motatau Complex rocks and rare Tupou Complex rocks. Mangakahia Complex rocks consist of the Punakitere (sandstone and some mudstone) and Whangai (predominantly mudstone with some sandstone) formations. The Motatau, found at Motatau near Dargaville and to the east of the Kaipara Harbour, is predominantly limestone with mudstone and sandstone, and of Eocene and Oligocene age. Serpentinite boulders also exist within these sedimentary rocks and have been mined for use as fertiliser. The Tupou is very similar to the Mt Camel terrane (see above) and may be a sheet of that terrane which got caught up in the allochthon.

AUTOCHTHONOUS ROCKS

On the Karikari Peninsula we have even more evidence for a link with East Cape. Uncomformably overlying the Mt Camel terrane on the peninsula is a collection of breccia, mudstone, sandstone and conglomerate called the Whatuwhiwhi Formation; this is included in the Cretaceous Matawai Group which is otherwise found in the Raukumara Peninsula. Overlying this is another formation, the Waiari, part of the Tinui Group, of chert and mudstone from the Late Cretaceous and Palaeocene that is equivalent to the Whangai Formation both of the Raukumara Peninsula and the Northland Allochthon, but it is not allochthonous (rather, it is 'in place' or autochthonous). Autochthonous rocks from the Late Cretaceous and Palaeocene are otherwise difficult to find onshore in Northland.

The Northland landscape

As a result of all this activity, hard basement (Waipapa) rocks, capable of forming relatively steep slopes (including eastern Northland's characteristic rocky headlands), are found on the surface in the eastern part of Northland where the remaining sediment has been eroded away. In contrast, further west is a hummocky terrain of less stable sedimentary allochthonous and more recent rocks, where the Murihiku terrane is deeply buried. Allochthonous and later volcanics form raised plateaux in the west, while in the centre of the north the Puketi and Omahuta forests cloak an elevated block of Caples terrane. Northland is indeed a very mixed-up geological jumble!

THE ERODING HILLS OF THE EAST

Submergence of Zealandia in the region that has since become the Gisborne District allowed sediment to build up there also; thanks to the onset of renewed uplift, these Tertiary sediments are now subaerial and the resulting rocks form most of the rocks to the southeast of the crests of the Raukumara Range and the Hinuera Ridge. As one travels south and east towards the coast, the rocks

left **While the crest of Mt Hikurangi, northern New Zealand's highest peak, is Torlesse terrane, it is surrounded by Matawai Group rocks.**

become progressively younger; the coastal areas were the last to emerge above sea level, so that both sediment deposition stopped earlier and erosion started later.

As a result, near the crest of the axial ranges the sedimentary rocks visible on the surface, directly overlying the Torlesse basement rocks, are those of the oldest of the cover rocks, the Matawai Group, which dates from the Middle to Late Cretaceous. Marine transgressive sequences, similar to those of the Te Kuiti Group, can also be observed in these rocks, resulting in beds of rocks of different types including sandstone, conglomerate and mudstone. Igneous clasts are also present within the Matawai Group. It would appear that in the west the rocks were formed in a continental shelf environment, but to the east it was in much deeper ocean. There is also a definite boundary (unconformity) between the Matawai Group and the Pahau terrane, called the Oponae mélange, which means that there must have been an interruption between the laying down of the Torlesse rocks and that of the Matawai rocks, although this boundary is not always consistent and so there is some debate about exactly what happened. Matawai Group rocks are also present at depth over a wider area to the south and east of where they outcrop on the crests of ranges, coming to the surface again in a small area between Gisborne and Tolaga Bay. As mentioned above, they are also visible on Northland's Karikari Peninsula.

After the Matawai Group was emplaced, several other sequences — both allochthonous and autochthonous — were deposited. At this juncture, the exact sequence and the variety of different names becomes rather a mouthful; many of these rocks are very patchily distributed.

The Matawai rocks were subsequently folded, uplifted and, in places, deeply eroded before being unconformably overlain by the

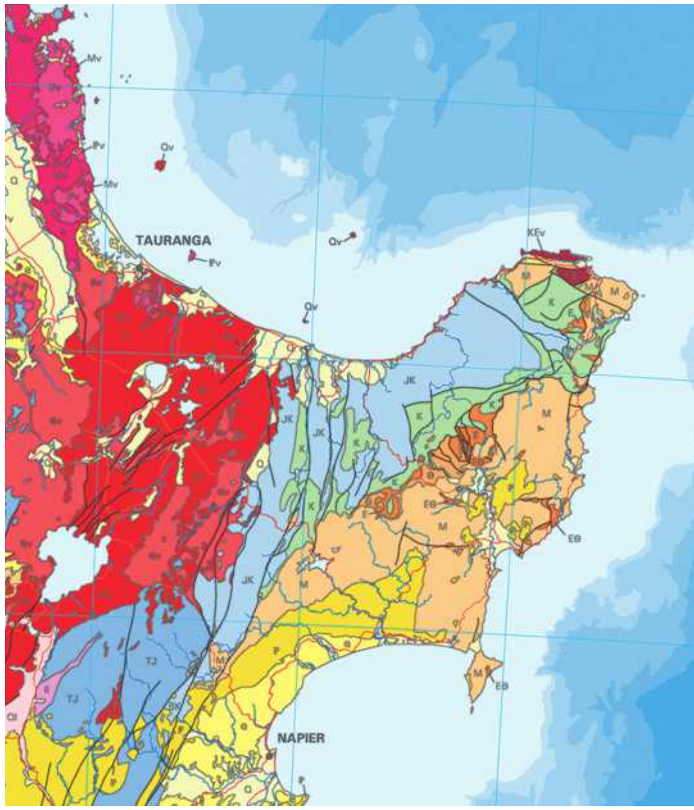


Figure 14 **The geology of the Raukumara area; the Jurassic and Cretaceous rocks are blue and green, with increasingly younger rocks from the Eocene (E), Oligocene (Θ), Miocene (M) and Pliocene (IP) present at the surface as one travels towards the coast. The volcanic lands (coloured red) around the Taupo Volcanic Zone lie to the west. Map courtesy of Lloyd Homer, GNS Science.**

Tinui Group (from the end of the Cretaceous to the Palaeocene). This group features yet another marine transgressive sequence, the earliest rocks (the more westerly Tahora Formation) being mainly massive sandstone and laid down from the level of beaches to mid-shelf; this changes as one goes east to the Owheno Formation sandstone and mudstone typical of deeper water, and in turn this is overlain by Whangai shale and mudstone, which is sometimes calcareous. Kirk's Breccia, from Kirk's Clearing in the mid-Motu valley, contains clasts with Late Cretaceous fossils.

Conformably overlying the Whangai Formation are Waipawa Mudstones,

left **The braided Waiapu River near Ruatoria (on the right of the picture) carries eroded sediment from the hills of the East Cape Allochthon. Gisborne District.**

of Miocene age. These shales may be economically important as they are promising in terms of possible oil and gas reserves. These rocks are in turn overlain conformably (i.e. without the discontinuity of an unconformity) by, predominantly, mudstones of Palaeocene to Oligocene age, the Wanstead and Weber formations of the Mangatu Group near Gisborne; those of the Wanstead Formation (deep-sea limestone and mudstone) contain a high proportion of smectitic clays (see the chapter on soils) which cause land made of this formation to be prone to slumps and erosion.

North and east towards East Cape are the rocks of the East Cape Allochthon, dating from the Cretaceous to the Oligocene. The alternating sandstones and mudstones of the Ruatoria Group are, in general, the allochthonous equivalent of the Matawai Group, although there are some autochthonous Ruatoria rocks in the lower Mata valley; later Tinui and Mangatu rocks are also present within the allochthon. This allochthon covers, variously, Torlesse, Matawai or autochthonous Tinui Group rocks. The Matakaoa volcanics, igneous rocks that correlate to Northland's Tangihua Group, are also present. Although among the oldest rocks of the allochthon, the Matakaoa volcanics are now at the top of the pile, thanks to the movement involved in its emplacement in the Early Miocene (in the same way that some older rocks overlie younger rocks in Northland).

From the North Island's Wairoa River valley east, one can find a succession of synclines, dipping first down then up (similar in form to the Kawhia Regional Syncline); from west to east one finds the Wairoa Syncline forming the low-lying Wairoa River valley, then the raised Mangaone Anticline which is in turn succeeded by the Nuhaka Syncline and then the Morere Anticline; finally, the land slips below the Pacific Ocean in the trough of the West Mahia Syncline.

THE NEXT GREAT UPLIFT: THE KAIKOURA OROGENY AND NEW ZEALAND

Around 43 Ma a convergent plate margin, between the Pacific and Indo-Australian plates, reactivated northeast of New Zealand. This 'crack' in the Pacific Plate probably occurred as a result of Australia's continued northern movement away from Antarctica, causing rotation in the area of New Zealand.

Uplift in the New Zealand area began around 25 Ma, the Late Oligocene. In the Miocene (23 to 5.3 Ma), the plate boundary between the Pacific and Indo-Australian plates became more significant in the area of Northland, causing compression and horizontal shortening of the land, and uplift began in earnest. The Hikurangi Trough, the convergent plate boundary where the Pacific Plate begins to descend under the North Island, has been present in the waters to our east for probably most of the last 23 million years.

This uplift has continued to accelerate, such that over the last 5 million years the whole of New Zealand has changed from only a few small islands poking above the waves to what we see now, a hilly and mountainous land. This uplift is often termed the Kaikoura Orogeny (after the place of the same name in the northeast South Island). It has not been a steady, equal uplift; the north has been subject to rifting, twisting, volcanism and mountain-building, as well as the occasional subsidence, in different places and at different times. Even today the Wanganui Basin to our south continues to subside, as do our two rift valleys, the Taupo Volcanic Zone and the Hauraki Rift.

Not coincidentally, at the same time (23 Ma) and in the same place (Northland) there was a revival of volcanic activity. Over time this activity slowly progressed southwards to the Coromandel and then to the central North Island, where it is most active now.

The most prominent feature (on land) of the plate boundary in New Zealand is the Alpine Fault of the South Island. This represents a line of contact between the two

below **Uplift has caused tilting of the previously flat Miocene sedimentary strata, while subsequent erosion has caused slumping at the sides and ends of each block of land, creating the landscape now visible inland from Wairoa. Some areas have also subsided. Pictured are Tolaga Group rocks east of Lake Waikaremoana, Wairoa District. Predominantly mudstone, a lip of harder sandstone forms the prominent strike ridge of the Ngamoko Range on the left from which the overlying, less-resistant mudstone has been stripped.**

plates in the central South Island where, instead of one plate subducting under the other, the two plates are pushing right up against each other. They are also sliding past each other, with the Pacific Plate moving in a southwesterly direction relative to the Indo-Australian. Over the last 23 million years, such movement on this fault has shifted the rocks on one side of the South Island 480 km away from the same rocks on the other side (those on the western side have moved northwards relative to those on the east), and this is the reason why Murihiku rocks are present in both Southland and the Waikato. However, over that same period of time there has been about 850–900 km of movement in total; the rest of the movement not taken up by the Alpine Fault has smeared, faulted and twisted the rocks on either side of it, including those of the north; this has given rise to rift valleys, vulcanism and earthquakes.

On a global scale, the Miocene is also notable for a gradual change from the warm climate of the Early Tertiary to the current climate, with yet more rapid cooling in the Pliocene just before the onset of the Pleistocene. In the Early Miocene, sea-water temperatures in our region were about 5–7°C warmer than today. Between about 14.8 and 14.1 Ma (Middle Miocene), Antarctica became separated from the other southern lands and, as a result, a continuous circumpolar current developed that continues to isolate Antarctica from warmer currents to its north. A major and permanent cooling step occurred, associated with increased production of cold Antarctic deep waters and a major growth of the East Antarctic ice sheet. Concurrently the West Wind Drift, the prevailing westerly winds that circle the globe in the latitudes of the Southern Ocean, developed.

RIFTING

As mentioned previously, around 20 Ma East Cape and Northland were contiguous, but East Cape has since been rifted southwards and eastwards, leaving in its wake volcanoes which are older in the north and younger in the south. Movement of the plate boundary eastwards away from Northland and Auckland also led to relative tectonic quiescence in this area compared with anywhere else in New Zealand; its nearest rival for low earthquake risk is, by no coincidence, that part of New Zealand furthest from the other side of the plate boundary: Dunedin and coastal Otago, and the Chatham Islands.

Because the Pacific Plate is sliding in a southwesterly direction beneath the Indo-Australian Plate in the South Island and, under our eastern seaboard, is still not that deep, it is pulling the crust above it and rotating East Cape in a south-southeasterly direction (Fig. 22). This movement has stretched the crust between Northland, Auckland and the Waikato on the one hand and the Gisborne District on the other, causing thinning (back-arc extension and rifting) in the area between the two (see Fig. 15 below). As a result, some areas of crust have simply dropped down en bloc, bounded by a fault on either side. We have two rift valleys: the Hauraki Rift, which extends nor-northwest from Taupo; and the rift valley of the Taupo Volcanic Zone (TVZ), the Whakatane Graben, which again extends from the Taupo region but this time in a nor-northeasterly direction, continuing to the northeast offshore of Whakatane. The northern Hauraki Gulf area, to the west of both rifts, continues to move away from East Cape by around 10 mm/year; the TVZ is the dominant locus of this movement, contributing about 8 mm/year of it.

Such back-arc rifting is common in the Pacific region; other classic back-arc basins include Antarctica's Bransfield Strait, between the South Shetland Islands and the Antarctic

Peninsula, caused by the subduction of the Pacific Plate under the Antarctic on the other side of those islands, as well as the Sea of Japan, once again behind the islands of Japan, which lie closer to the subduction zone (see Fig. 21).

The Hauraki Rift, bounded by the Firth of Thames Fault on the west and the Hauraki Fault on the east, is quite obvious even from the ground when one looks up from the Hauraki Plains to the straight edge of the Kaimai Range rising to the east. This rift began opening in the Late Miocene and continues to this day, with subsidence measured at 1.5 mm/year along the Firth of Thames Fault; sediment and pyroclastic flows from volcanic eruptions have been gradually filing the basin. The hot springs at Te Aroha arise from water percolating through the crushed (and therefore porous) rock of the Hauraki Fault at the eastern margin of the rift and, on the other side of the Hauraki Plains, similar hot springs emerge at Miranda, likewise percolating up through the porous, crushed rock of the Firth of Thames Fault on the western margin of the rift. Finally, under the centre of the plains is another fault, the Kerepehi, and there are also several transverse faults occurring at right-angles to all three. The Kerepehi Fault is one of only two faults in this area thought to be still active, the other being the Wairoa Fault in the Hunuas; there are no known active faults in the western Waikato or, for that matter, in the relatively tectonically quiescent Northland, although new faults are being found all of the time, such as under Christchurch!

This type of landform is termed a horst and graben system. Fault-bounded blocks of crust are each moving vertically relative to their neighbours; the boundary between two blocks is a normal fault. The block that moves up relative to its neighbour (the horst) is subject to more erosion as a result, progressively being stripped of more recent sediments to expose older rock. Conversely, the block that sinks (the graben) becomes covered in more recent sediment; grabens form the Waikato's sedimentary basins. Offshore we have other, much larger, such sedimentary basins (with up to 8 km of sediment) dating from the subsidence in the Cretaceous and Cenozoic, the Northland and Taranaki basins off to our west and the Raukumara and East Coast basins to our east; the King Country Basin, from the same period, is onshore and its deposition is discussed later in this chapter, as is the Waitemata Basin.

Not only is the Hauraki Rift a graben (actually, it may be up to three half-grabens, given the presence of at least one fault, the active Kerepehi, in the middle), but it is also only one of a whole series of horsts and grabens traversing Auckland, Waikato and the Coromandel. If one takes a transect across the north Waikato and Hauraki plains, going west to east, one first encounters the horst of the west Waikato hills, then the graben of the Hamilton Basin, Lower Waikato Basin,

below **Looking west from the Kaimai Range over the Hauraki Rift (filled in by the Matamata Plains), to the hills surrounding the Hamilton Basin. Prominent on the left is Maungatautari; in the right middle distance are the Hangawera Hills and in the right far distance, on the other side of the Hamilton Basin, Mt Pirongia and the hills of the western Waikato. Matamata-Piako District.**

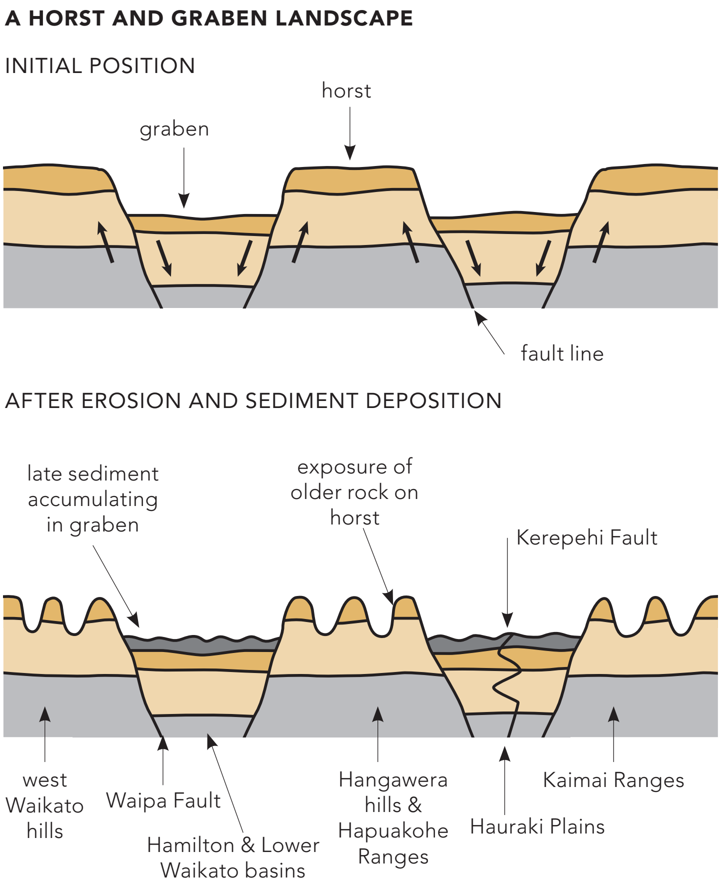


Figure 15 **Formation of the horst and graben landscape of the Waikato, with the blocks of sedimentary rocks pushed up becoming stripped of their surface sediments to expose older underlying rocks such as those of the Te Kuiti Group and even basement terranes (e.g. the Hapuakohe Range). Those that were downfaulted to become basins, including the Hamilton Basin and the Hauraki and Matamata plains, became covered in later Quaternary sediments.**

Manukau Lowlands and Manukau Harbour. Easily visible on the eastern side of the Whangamarino Fen is the Maungaroa Fault, which separates that low-lying fen from the next horst containing the uplifted area from Waiheke and Motutapu Islands in the north, through the Hunua and Hapuakohe ranges to the Hangawera hills east of Hamilton. In turn that is bounded by the Firth of Thames Fault and we drop into the Hauraki Rift containing the Hauraki and Matamata plains as well as the Firth of Thames, before rising again in the Coromandel and Kaimai ranges as well as Great Barrier Island on the other side. There are interruptions to this sequence of alternating lowlands and highlands. For instance, the later Auckland and South Auckland (around Pukekohe and east to Bombay) volcanic fields interrupt the 'Waikato' graben, as do the Taupiri and Hakarimata ranges, formed from a block of rotated Murihiku terrane (itself an anomaly, as previously mentioned). In general, the horsts have been stripped of their more recent sediments by erosion, such that the underlying basement greywacke rocks (and Miocene volcanics, in the case of the Coromandel Peninsula and Great Barrier Island) are exposed, whereas the grabens have been filled up with Cenozoic (Tertiary and Quaternary) sediments.

Aucklanders might be interested to know that before the Hauraki Rift downfaulted, the Clevedon River used to flow from the Coromandel across the Firth of Thames area westwards to flow out in the area that is the

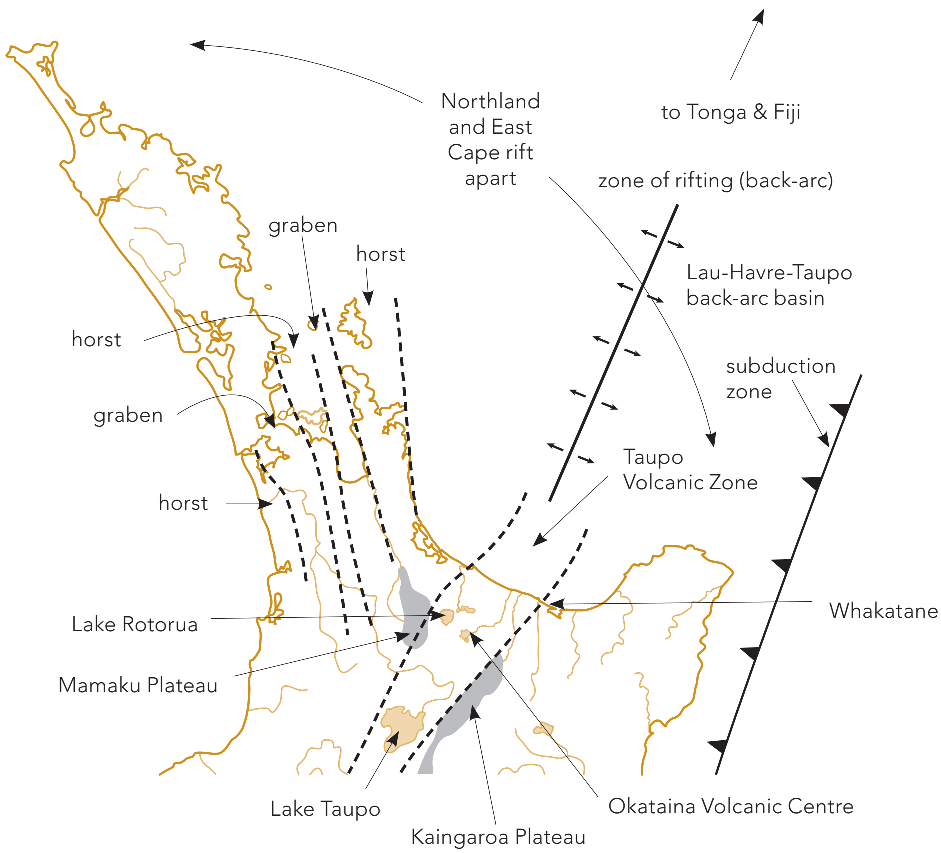


Figure 16 **The two rift valleys of northern New Zealand are shown, along with the various horsts and grabens of the Waikato. The Mamaku and Kaingaroa plateaux flank the Taupo Volcanic Zone (TVZ), being covered in ignimbrite from eruptions in that region. Back-arc rifting (see also Fig. 20) continues from the TVZ almost as far as Samoa. An effect of this rifting is to separate Northland from East Cape.**

Manukau Harbour today.

The other rift forms the Whakatane Graben, which contains the TVZ. It is bordered at the coast by Matata and Whakatane (and filled in, along this coast, by the Rangitaiki Plains). This area continues to sink as it rifts, although previous volcanic eruptions and alluvium have filled in the sinking land and hide this fact from casual observation; Taupo and Okataina remain highly active volcanic centres (see below).

right **The downfaulted Whakatane Graben (Taupo Rift) of the Taupo Volcanic Zone occupies the middle distance of this panorama, with the dacitic cone of Mt Edgecumbe in its centre. This rift is being filled in by alluvium to form the Rangitaiki Plains in the right middle distance. Note the higher land on each side of the graben, in the foreground and background. Whakatane District.**

left **A spectacular landform on Mt Manaia, Whangarei Heads (Whangarei District). Originally erupting subaerially as an andesitic cone between 21.5 and 16.1 Ma (Early Miocene), now only remnants of the base are left.**

VOLCANIC ROCKS OF THE LATER TERTIARY (NEOGENE)

As a result of the Pacific Plate's collision with and subduction under the Indo-Australian Plate in the late Oligocene, subduction-related vulcanism commenced. The descending slab of Pacific Plate, 5 km thick, features oceanic crust with a high water content, both as pore water and as the hydrous part of hydrated minerals. When such a slab reaches depths of around 70–100 km, which, at present, occurs under the TVZ, it undergoes chemical reactions due to the extreme heat and pressure that this descent subjects it to (termed metamorphic dehydration reactions); these expel the water upwards, followed by other volatile components such as carbon dioxide. The expelled water lowers the melting point of the asthenosphere over the slab (Fig. 20).

The result is a gas-rich magma which, given that liquids are incompressible and lighter than solids, then rises towards the surface. The volcanoes produced tend to be andesitic rather than basaltic as their magma contains a relatively high silica content, being derived from a mix of mantle and crustal sources. This also tends to make their eruptions relatively violent. Both these characteristics are in contrast with the basaltic leaky-crust-type volcanoes of Auckland and Northland, which do not derive from subduction and therefore do not include as much silicon-containing sedimentary rock.

Because of this subduction, directly after (between 20 and 15 Ma) the Northland

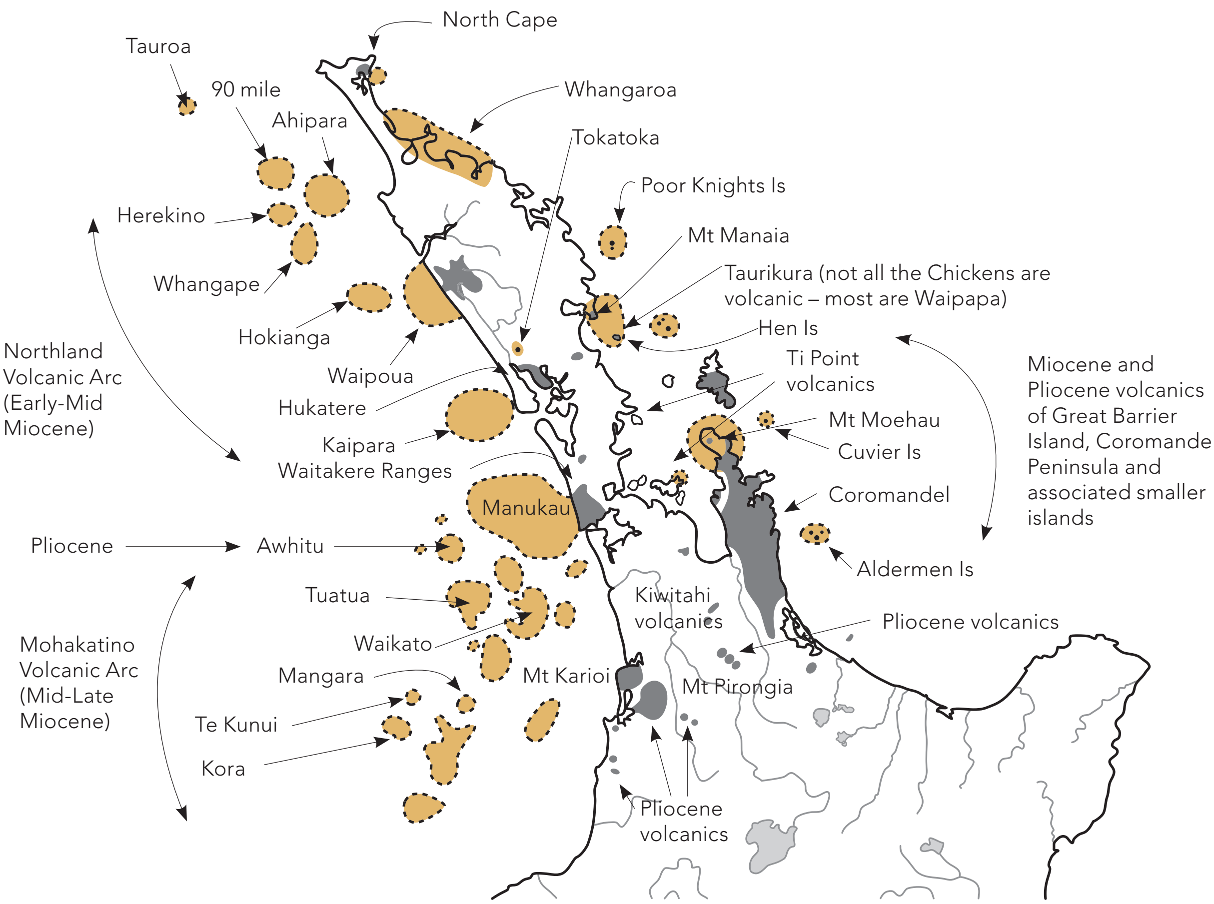


Figure 17 **Miocene and Pliocene volcanics of the Later Tertiary.**

Allochthon was emplaced, two chains of volcanoes began erupting 40 km apart, first in Northland and East Cape (the two being contiguous at the time) and then further south. The Northland volcanics tapered off after 16 Ma as the line of subduction moved eastwards in the Middle Miocene, with consequent rifting away of Northland from East Cape (Fig. 16). This left Northland looking perhaps like Vanuatu does today: a group of volcanic islands. Indeed, up to about 5 Ma there was little land in the North Island at all bar volcanic islands; even the North Island's highest peak, Mt Ruapehu, sits on a plinth of marine sandstones and siltstones of Miocene and Pliocene age.

The western chain, 400 km long, erupted off the present west coast of Northland (from about 23 to 15.5 Ma), extending down as far as Taranaki where the Mohakatino Volcanic Arc was most active between 14 to 11 Ma and as late as 5 Ma; these were large, underwater andesitic volcanoes including the large Waipoua, Kaipara, Manukau, Awhitu and Waikato volcanoes of the Early Miocene Waitakere Group. Pillow lavas oozed out from these volcanoes under the sea (e.g. at Maori Bay near Muriwai), eventually growing sufficiently extensive to surface above sea level, preserving fossils in their ash shower. Onshore remnants of these volcanoes include the basaltic Tutamoe Plateau which

underlies much of the Waipoua Forest (a remnant of the Waipoua Volcano), and the Waitakere Ranges, once the eastern flank of the Manukau Volcano (also known as the Waitakere Volcano). Rocks from the latter would occasionally slide down into the Waitemata Basin, giving rise to the Parnell Grit present within Waitemata Sandstone, visible today behind Auckland's Parnell Baths (a type locality). Remnants of that part of the chain lying off the western Waikato coast are visible onshore as the volcaniclastic sediment of the Mohakatino Formation, on the coast near Awakino. These rocks were buried by up to 4 km of sediment in the Late Miocene and Pliocene, but thanks to erosion have now resurfaced.

Slightly further east are some smaller volcanoes which have now mostly been eroded away; remnants are still visible (e.g. Maungaraho) amidst the limestone countryside between Tokatoka and Dargaville.

The second, eastern chain started erupting around the same time, 23 Ma, initially along the east coast of Northland and increasingly later as one travels south to Great Barrier Island and the Coromandel, again due to the subduction zone gradually shifting away from Northland. The eruptions in Northland created spectacular headlands and islands, particularly around the Whangaroa and Whangarei harbours (examples being Whangarei Heads and Hen Island); the Coromandel is almost completely volcanic,

top **Tauranikau, a volcanic plug in the Kauaeranga Valley, Thames-Coromandel District. This dome of rhyolitic lava plugged a volcano active about 8 Ma. Eventually the volcano was eroded away, exposing the plug.**

middle **The flat top and dissected sides of the Tutamoe Plateau, the remnant of the Waipoua Volcano, Far North District.**

bottom **Basalt lava columns (left foreground), with eroded boulders and, high on the cliff, a second layer of lava. Near Muriwai, west Auckland.**

although in the north some Jurassic Waipapa basement rock is visible on the surface. The first Coromandel volcanoes erupted in the west (the Coromandel Group) about 20 Ma; these were mostly andesite and dacite volcanoes. The most prominent hill, Te Moehau, is diorite, the underground (plutonic) equivalent of andesite, as erosion has removed the entire volcano down to the previously underground magma chamber; Cuvier Island is similarly plutonic rather than volcanic. Diorite is similar to granite, formed as magma cools and hardens without reaching the surface; it is subaerial only due to later erosion and is the source of the 'Coromandel granite' used on important buildings (including Parliament House) and monuments. About 10 Ma, activity in the Coromandel shifted to the eastern side of the peninsula, the Whitianga Group, producing multiple rhyolitic domes, huge calderas and sheets of ignimbrite. Gradually the centre of terrestrial volcanism shifted southeast in the Pliocene (5–2 Ma) to form the Kaimai Range; the last volcano in this sequence was Tauranga's Mt Maunganui (Mauao).

Hot water, carrying dissolved minerals, seeped up through cracks in the andesitic rocks near the end of this eruptive sequence (around 6 Ma); these cracks became lined with veins of quartz containing hydrothermal deposits of minerals when they precipitated out of solution. The most well-known such mineral in the Coromandel is gold, one of the early sources of wealth for the new Auckland Province in the 19th century and still being mined at Waihi, but other minerals such as silver are also present. At the time, the area would have looked like Rotorua does now, a geothermal field.

Another small set of basaltic and andesitic volcanoes, related to the Coromandel Volcanic Arc, erupted on the western side of the Hauraki Plains and Firth of Thames in

top **Miocene Coromandel Volcanic rocks at the summit of the Pinnacles (the author with family); this is the Minden Rhyolite Subgroup of the Whitianga Group, which consists of rhyolite flow and dome complexes with associated tuff and breccia. Thames-Coromandel District.**

bottom **The rugged volcanic landscape in the interior of the Coromandel. Upper Kauaeranga Valley, Thames-Coromandel District.**

the Late Miocene. These are known as the Kiwitahi Volcanics and extend from Waiheke Island in the north (14 Ma) to Maungakawa, near Morrinsville, in the south (5.5 Ma). The southern cones of this group can be connected by a straight line, the significance of which is unclear. Waiheke residents and visitors should note that the exposed volcanic remnants at Stony Batter are not from this group, however, but from the later Miocene Ti Point Volcanic Group; they are mainly basaltic, resting upon andesitic breccia from the Kiwitahi Group. The Ti Point Group can also be found (unsurprisingly!) at Ti Point and the hills to the north and northwest, between Matakana and Pakiri in northeastern Auckland; probably these are the remnants of quite a widespread basaltic volcanic field.

THE MIOCENE AND PLIOCENE: SEDIMENTARY ROCKS

IN THE EAST: SOFT, UPLIFTED ROCKS

Compared with many of the world's mountain ranges, the Southern Alps are very young (around 5 million years old) and the North Island's extension of the Southern Alps, the axial ranges which rise parallel to the east coast, are even younger; the Gisborne District only became subaerial, let alone mountainous, in the Middle Pliocene (about 3 Ma). The North Island axial ranges, brought about by compression of the crust along the Hikurangi Margin, have been building for perhaps 2 million years and are still rising at a rate of around 4 mm/year, although erosion continues to wear down the soft rock. Because the ranges only became subaerial such a short time ago, the hills of the Gisborne District are still covered in 'papa'; these soft, grey, easily eroded Miocene and Pliocene mudstones and sandstones have long since been eroded away from the higher and older Alps of the South Island.

As one goes in a southeasterly direction from the crest of the axial ranges, the rocks on the surface become gradually younger. Since the sediments that formed them were deposited underwater, the land further in that direction must have risen above sea level only very recently. In fact, this whole area is continuing to rise up out of the sea — such as happened abruptly in the Napier earthquake of 1931.

In the Early Miocene, the pelagic, clay-rich mudstones and limestones of the Mangatu Group were replaced by terrestrial-derived (terriginous) sediments, much thicker and composed of sandstone and mudstone together with some conglomerate and tuff of Miocene age (the Tolaga Group) to Pliocene age (the Mangaheia Group consists of rocks from the Latest Miocene to the Early Pliocene). This sudden change, a marine regression, was caused by uplift from tectonic activity due to the emergence of the active plate boundary between Northland and Marlborough, the same one which emplaced the Northland and East Cape Allochthons. Volcanic ash is present in some of these strata, from volcanoes active in the Coromandel area. There are also some limestones within the Mangaheia Group, visible near Gisborne and Wairoa.

In general, therefore, as one heads towards the coast both the Matawai Group and the

East Coast Allochthon rocks become buried by later mudstones and sandstones that are generally much more susceptible to erosion than the greywacke of the Torlesse Supergroup. This tendency has been at the heart of the erosion problems experienced in this district since deforestation which have led to a pine plantation reafforestation project in an attempt to overcome this; it has also given us spectacular sheer coastal cliffs, such as those around Tolaga Bay, and the broken hills incised by deep river valleys that are such a characteristic feature of the Gisborne District.

The amount of erosion and sediment flowing down the rivers of the Gisborne District is astonishing; the Waiapu River, which runs past Ruatoria, has one of the highest sediment loads of any river in the world (35 megatonnes/year); this is 100 times the amount of sediment delivered to the Hauraki Gulf. The rivers of this district account for 58% of the entire North Island sediment yield.

top **Uplift and erosion: Gable End Foreland (named by Captain James Cook), comprising alternating mudstone and sandstone (white) beds of the Late Tolaga Group. The sandstone contains volcanic ash, probably derived from the Miocene Coromandel Volcanics. These rocks have been tilted 90°. Gisborne District.**

bottom **The Panekiri Bluffs, Lake Waikaremoana (Te Urewera), showing hard, metre-bedded sandstone horizons that have been stripped of the softer mudstones that dominate the Tolaga Group, by erosion. The mudstones are visible on the less-steep slopes and valleys (at least, where not hidden by forest!). Wairoa District.**

THE SEDIMENTARY ROCKS OF THE WEST

When the converging plate boundary first became active northeast of Northland in the late Oligocene, it caused rocks in the northern Waikato to be uplifted and tilted westwards, eroding the Te Kuiti Group subaerially. However, in the early Miocene several 'basins' in the west started to sink again and once more became submarine; this was caused by warping of the Earth's crust induced by the onset of subduction and uplift further east. Today, such 'warpage' is currently forming the basin that separates Whanganui, on the North Island's southwest coast, from Nelson in the South Island's far north.

THE WAITEMATA BASIN

In the north, in the early Miocene, the basement rock surrounding the Auckland area, from Pirongia to the Brynderwyns, gradually sank relative to its neighbours to its north, south and east (the Coromandel), forming the marine Waitemata Basin. This gradually filled up with sandstone and sandy siltstone, which has now been uplifted and is visible in and around Auckland in places such as the cliffs along the North Shore and Tamaki Drive; known as Waitemata Sandstone, it uncomformably overlies Te Kuiti Group rocks. North of about Waiwera the Waitemata Group contains relatively more volcanic material, rendering it more resistant to erosion; hence, one encounters higher hills, steeper slopes and larger cliffs. Unlike areas to the south, this area did not undergo further subsidence in the Middle Miocene, making it much less complicated than those other areas, as we shall come to see!

The Waitemata rocks are particularly interesting as they were formed in a very similar way to the basement rocks of the Eastern Province, being mainly sandstone

top **Coastal erosion in the soft Waitemata Sandstone, Parnell, Auckland.**

bottom **A small anticline at the northern end of Eastern Beach, Auckland, in Waitemata Group rocks.**

laid down in a marine basin, with small-scale turbidity currents episodically depositing volcanic debris (Parnell Grit, observable in the cliffs behind the Parnell Baths) from the volcanoes to the west. Subsequent uplift has caused folding and distortion of the sediment layers, albeit on a small scale, such as the synclines and anticlines visible over the course of a few metres at the northern end of Eastern Beach. The sandstone cliffs lack vegetation, exposing the structure of the rock, and are easily accessible to our largest population.

THE KING COUNTRY BASIN

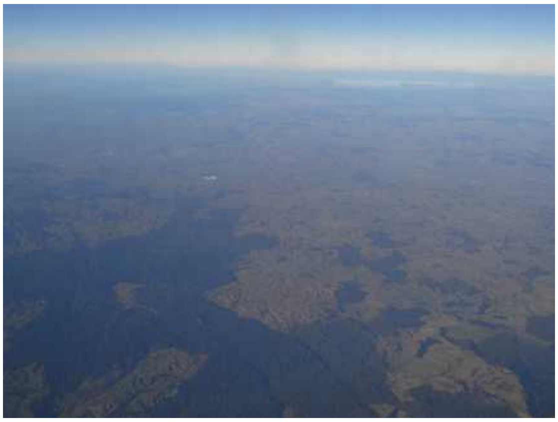
Still mostly underwater despite the renewed uplift, from the Miocene onwards yet more sediments accumulated on top of the Te Kuiti Group in the west, with progressively greater amounts of overlying sediment the further one travels south of Te Kuiti. This indicates that, in the Waikato generally, the land rose up out of the sea first in the north and then in the south.

One area where sediment accumulated was the King Country Basin, located in the southwestern Waikato and King Country from Te Kuiti south, west of Pureora Forest Park and extending into Taranaki. It and the adjacent Taranaki and Wanganui basins, to our west and south, respectively, underwent four different depositional episodes in the Miocene, broken by renewed uplifts. This irregular uplift and subsidence, variable from place to place, makes the geology very complicated. The rocks here do demonstrate how different rocks are deposited as sea level and distance from the coast varies and as the land both sinks (transgressive marine sequences) and rises (regressive sequences), as well as how movements on faults can abruptly change the rock sequence. The absence of certain rocks in some places, despite their presence in others — producing a gap between younger and older rocks — helps us determine which areas were subaerial and eroding and which remained protected from the elements in a mostly submarine environment, with continuing sediment deposition.

The first depositional sequence formed the rocks of the Early Miocene Mahoenui Group. In the main these are mudstones from bathylal (intermediate) ocean depths, deposited as an extensive fan from turbidity currents (as mentioned above) in an area from Otorohanga south that was subsiding faster than other areas. This group forms hills which are prone to slumping and lie (conformably) on top of Te Kuiti Limestone, such as at Totoro Gorge. This deposition came to an end around 20 Ma with inversion and erosion due to the last major thrust movement on the northern part of the Taranaki Fault, offshore to our west.

The second phase began when the Ohura Fault, halfway between the coast and Lake Taupo (roughly along the line of the Ohura River), became active in the early Miocene. The block to the southeast of this fault was uplifted above sea level and the Mahoenui Group continued to erode there. However, on the northwest side of the fault, the basin filled with sediments derived from, at least in part, the uplifted block, forming the Mokau Group. Therefore the Mokau Group overlies the Mahoenui Group northwest of this fault, but not to its southeast.

The earliest formation in the Mokau Group is the transgressive Bexley Formation, comprising mainly sandstones. This is followed by the Maryville Coal Measures, which contain an intervening fluvial (from rivers) and shoreface (from the coast) succession of sediments. We can therefore infer that, at this time, the sea level was going up and down. The final formation is an upper regressive shoreface sandstone, the Tangarakau Formation, mostly consisting of muddy sandstone and siltstone, but also with



above **The far southwestern corner of our area. Lake Taupo is in the right background, behind the ridge of the Pureora Forest Park. Note the 'choppy' hills.**

some coal measures. A regressive sequence is the opposite of a transgressive one; it represents deposition that occurred as land was being lifted out of the sea.

In some places, especially further west towards the Herangi High (an area bordering the south Waikato's west coast where the basement rocks come closer to the surface, being exposed as the Herangi Range), the Bexley Formation lies directly upon the Murihiku basement rock rather than older cover rocks, indicating erosion of older cover sediments prior to the deposition of the Bexley Formation.

The deposition of the Mokau Group was halted by Middle Miocene uplift and hence subaerial erosion, but slightly later in the Middle Miocene, subsidence occurred for a third time, causing flooding of the southern part of the basin and resulting in yet another transgressive sequence in the form of the sandstones and siltstones of the Middle and Late Miocene transgressive Otanui Formation, thickest east of the Ohura Fault and the main component of the Whangamomona Group of the northeastern corner of Taranaki, present also just to the north of Taumarunui.

THE TARANAKI BASIN

Right on the coast, to the west of the Herangi Range, is a small onshore portion of the Taranaki Basin. Formed by Miocene rocks similar to those of the King Country Basin, Early Miocene rocks of the Manganui Formation directly and unconformably overlie Murihiku rocks in the north and Bexley Formation rocks further south, and are contiguous with the Tangarakau Formation further east of Awakino. They are massive blue-grey mudstones with some sandstone and concretionary horizons, visible on the coast between Mokau and Tirua Point.

Middle and Late Miocene rocks in the same area (the Wai-iti Group) are analogous to the Whangamomona Group and include limestones and sandstones (the earliest, the Tirua Formation), volcaniclastic sandstones and mudstones (the Mohakatino Formation), the Middle to Late Miocene Mt Messenger Formation, mainly sandstone, and the late Miocene Urenui Formation siltstones south of Awakino. The latter two formations are part of a regressive sequence as, in the Late Miocene, North Taranaki became dry land due to sediment supply from the proto-Southern Alps, where continent–continent collision was developing and eventually overcame subsidence. The continental margin shifted northwards as a result of this sedimentation.

In the Early Pliocene a shallow sea filled the basin between Taranaki and the Kaimanawa Range at the very southern terminus of our area, with its northern boundary at Moawhango. This sea filled with soft sea-floor mud, giving rise to a plateau on top of which Ruapehu emerged much later. In the southeast, our land emerged from the sea no later than 2.4 Ma, which goes to show just how young the North Island's tallest mountain and its highest plateau really is!

THE QUATERNARY

Compared with the previous spans of geological time the Quaternary is very short, starting only 2.59 Ma with the onset of the Pleistocene and continuing to the present day; however, it has left as great a mark on northern New Zealand as any other. The Pleistocene represents the era we colloquially call the Ice Ages and follows the Pliocene, the gradual cooling at the end of the Tertiary. The Holocene, dating from 12 thousand years ago (ka), is the epoch in which we live, beginning when the most recent glacial period or stadial (a cooler period less intense or prolonged than a glacial period) came to an end; more glacial periods may well follow in the future, although next time humanity may play a role.

In the Pleistocene not only did temperatures plummet but, because massive amounts of water were locked away as ice, mainly on the continents of the Northern Hemisphere, sea levels also fell; one could have walked to Great Barrier Island from the mainland during the middle of the glacial periods. As the last glacial period ended, over the period between 20 and 6 ka, the sea rose 125 m; hence our present coastline, including all modern harbours and estuaries, dates only from about 7 to 10 ka when the sea level rose to approximately its present position. One of the most distinctive features of the coastline of our current interglacial (the warm period between glacials), the Flandrian, is the presence of drowned river valleys or rias;

above **A river valley in the last glacial, now filled with sea water (a ria) of the Manukau Harbour, Mangere, Auckland.**

rivers that once ran out along land exposed by the lowered sea level of the glacial in places like the Bay of Islands or Auckland, such as that which ran along what is now the Waitemata Harbour, became 'drowned'. As the sea level rose, it flooded these valleys, turning them into the harbours and bays we know today. Some smaller tributaries are still apparent at a higher level, such as, for the Waitemata, the Whau and Tamaki Rivers and Lucas Creek. Flat land at the edge of the coast, such as the Rangitaiki Plains and our various beach resorts and sand-spits, also date from this time as the alluvial sediment only then began filling in the embayments occupied by the sea after it rose to its peak following the end of the Pleistocene. It is noteworthy that a sea-level rise of 0.18–0.59 m in the decade 2090–2099 above that in 1980–1999 was forecast by the Intergovernmental Panel on Climate Change (IPCC) in 2007; further changes in the coastline are therefore likely.

Over the Quaternary the Taupo Rift has continued to stretch and the crustal thickness has decreased from 25+ km to 16 km. The present rate of extension at the southern end of the TVZ, where it abuts the North Island Fault System, is 2.3 mm/year, increasing to about 15 mm/year at the Whakatane Graben; this differential is causing the continued block rotational movement of East Cape away from Northland. Furthermore, this rifting and its associated volcanoes are one of the major features of the Quaternary of the north.

SEDIMENTS OF THE QUATERNARY

SANDY COASTAL SEDIMENTS

Given a source of sand (such as from the sea, the surrounding land, or the shells of molluscs and other such creatures) sand dunes accumulate best in sheltered coasts where there are prevailing onshore winds. Rivers are also an important source of (fluvially transported) sediment, depositing their loads into the sea. Wave action then pushes the sand along the coast and onshore. At low tide, dry sand is blown inland to accumulate and become trapped by vegetation on the seaward-facing dune slope, the foredune. There may be other dunes further back, often older and more stable; the hollows between them may fill with water if the water table is high. Dunes can change dramatically and suddenly, however. If strong winds push through the foredune either directly or by increasing wave erosion they can cause a 'blowout', allowing sand to travel far inland. This may occur more commonly if humans have weakened the foredune structure, for instance by trampling and otherwise harming the sand-binding vegetation.

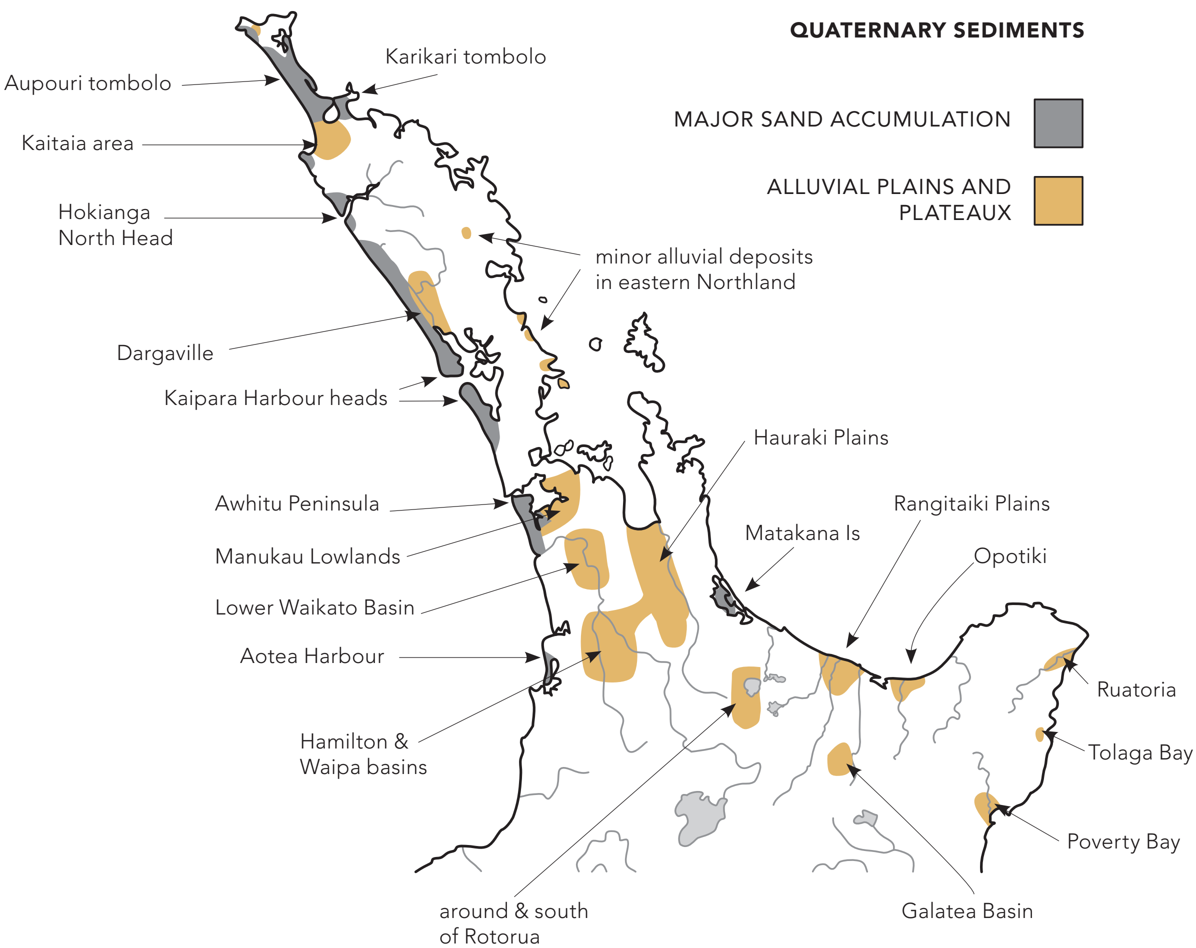
One of the most important processes in the formation of beaches is longshore drift; sediment carried by offshore currents is picked up when the current is travelling more quickly and deposited again when it slows down, often as the current heads into

below **The sandy barrier of the Awhitu Peninsula, southwest Auckland.**

deeper water. This movement causes the extension of sand bars across river mouths and the creation of tombolos, sand spits that connect former islands to the mainland. The largest such tombolo is the Aupouri Peninsula which connects the former island of Te Paki to the Kaitaia area; obviously this required a huge amount of sediment. Smaller tombolos include those that connect 'the Mount' to the mainland and Devonport to the rest of the North Shore, as well as the Karikari Peninsula in Northland.

Vast quantities of sandy sediment were laid down during the Pliocene and Pleistocene. The Pleistocene in particular was very windy; the most obvious sedimentary relics of the action of its particularly strong prevailing westerly winds are the huge barriers of sand dunes which form almost the entire west coast of the region north of Port Waikato. These sandy barriers have walled off the Manukau, Kaipara and Hokianga harbours and formed the sand bars at the entrance to these harbours which have caused so many shipwrecks, especially in the early days of European settlement. The west coast sand derives predominantly from sediment carried

Figure 18 **Quaternary sediments of the upper North Island. Major inland and coastal plains are indicated, all of which have filled with alluvium with the exception of the volcanic Kaingaroa Plateau. Large areas of sand accumulation are also noted; these are particularly prominent on the west coast, forming peninsulas that enclose harbours such as the Kaipara and also the large Aupouri and Karikari tombolos.**



above **Sand hills form the North Head of the Hokianga Harbour, Far North District.**

up from the erosion of Taranaki by ocean currents, volcanic debris carried down the Waikato River, and material from erosion of the sedimentary Mesozoic basement rocks. In the earliest (Pliocene) phases of sedimentation, before it was cut off from the west coast by the current basin and range topography of the Waikato, Coromandel Volcanic Centre debris was probably also important.

The alignment of the coastline, which gradually becomes more normal (i.e. perpendicular) to the direction of wave approach in western Northland and Auckland, probably also slows down longshore drift of sediment and allows sediment to settle. It would also seem that in order for a barrier to form, the slope from the shore to a depth of 25 m cannot exceed 1°.

One of the most obvious characteristics of much of the west coast sand is its black colour. Known as ironsand — technically, titanomagnetite sands — it predominantly originates from the andesitic Mt Taranaki and rhyolitic volcanic rocks of the TVZ, washed down the Waikato River. As one goes further north, this black sand disappears; at South Kaipara Head and further north, the sand looks yellow instead. As mentioned previously, the sand keeps moving; every year 30,000 tonnes gets added to Whatipu but is taken away from Awhitu. There may once have been a sandy stretch of land similar to Whatipu off the coast of the Awhitu Peninsula; this sand has now moved over to Whatipu and in time will continue to move north; one day, no doubt, the Whatipu wetlands will move on to Piha.

The sand deposits of the Pliocene form the Awhitu Group, overlain by the less consolidated and cemented Karioitahi Group; they extend somewhat discontinuously up the Waikato coast (being broken by headlands of Murihiku, Te Kuiti and volcanic rock) from just south of Kawhia Harbour to the Waikato River. North of there the interruptions are few bar the Waitakere coastline, Maunganui Bluff and the headlands between the Hokianga Harbour and Ahipara Bay; in the far north these sands also extend down the east coast, as they form the tombolos of the Aupouri and Karikari peninsulas.

Along the east coast there have been episodes of large amounts of sediment being fluvially transported down to the Bay of Plenty coast immediately after volcanic eruptions in the TVZ. At times the Waikato River has also emptied into the Firth of Thames, depositing its load there to fill in the Hauraki Rift. However, there is generally less fluvial sediment available in the east, particularly in the Hauraki Gulf and Northland, less wave and wind energy driving sediment ashore

and less effective longshore sediment supply. As a result, large barriers are less common than on the west coast except in well-defined sediment traps such as Poverty Bay, where the embayment traps sediment from offshore, longshore and fluvial sources. Similar processes of sediment trapping have also formed the Ohiwa Harbour near Whakatane and Northland seaside playgrounds such as the Karikari Peninsula and Omaha Beach. However, the largest barrier island in New Zealand, Matakana Island, and the nationally renowned Mt Maunganui beach, are in the east, cutting off the drowned landscape of Tauranga Harbour from the sea. This area is conducive to such a barrier because of abundant sediment supply, a moderate offshore gradient, moderate wave energy and a low tidal range. Also, the coast at this point becomes more normal (perpendicular) to the predominant northeasterly wave approach, similar to Northland's west coast, trapping sediment here. The sands on the eastern side of Northland are notably whiter than those on the west as they have a higher silica content (95% silica vs 60% silica on Ninety Mile Beach); as a result, the sands along Northland's east coast from Bream Tail to Cape Rodney have been mined for use in building aggregate and Parengarenga's very pure sand is barged to Auckland to make glass.

Sand can come and go, of course. Ohiwa Spit propagated between 1867 and 1911 and a hotel and town was built on it; these had to be abandoned by the 1940s due to erosion. The spit then stabilised again and, almost unimaginably, attempts at further subdivision

above **Unconsolidated sand dunes. Te Paki, Far North District.**

were made in the 1950s. Similar coastal erosion has occurred at the northern edge of the upmarket Omaha sand-spit, and future sea-level rise may pose a big threat to such low-lying coastal regions.

The Gisborne District is notable for the amount of debris that its rivers carry, forming some of our most fertile alluvial soils including the Poverty Bay flats as well as smaller areas in locations such as Tolaga Bay. Such sediment is generally finer-grained than that derived from the sea, being composed of silt particles as opposed to sand grains.

Silt is also a feature of estuarine waters, as their calmness allows the finer silt grains to settle more readily, giving rise to mudflats as opposed to sandy beaches. Indeed, the river valleys which filled with water at the end of the last glacial period (the rias) have been filling in ever since, as alluvium is deposited off nearby slopes, carried down rivers and washed in from the sea; witness the flats around the Wairoa River near Dargaville and even the shallowness of the Waitemata Harbour between Mission Bay and Rangitoto Island; assuming static sea levels, one day this will also be dry land (there aren't many big, sediment-laden rivers flowing into the Waitemata, so this is taking a long time). Rivers such as the Waikato have also brought with them volcanic ash and pumice from the Central Plateau, filling in low-lying basins such as the Hauraki Plains and Hamilton Basin.

below **The productive alluvial flats of Poverty Bay, Gisborne District.**

The most recent depositor of alluvium is, of course, man, through activities such as reclaiming land for wharves and filling in hollows to create flat surfaces for everything from roads to playing fields.

In summary, the outline of our present coastline has been mostly determined by the sea-level rise at the start of the current interglacial and infilling with alluvium; future rises in sea level may change it again.

IN THE BASINS OF THE WAIKATO

The graben that is the Hamilton Basin (also referred to as the Middle Waikato Basin) was also covered with sediments in the Quaternary and is now the site of northern New Zealand's second largest city; similar downfaulted basins covered in similar sediments include the Hauraki Plains, the Waipa Basin (south of Te Awamutu) and the Lower Waikato (or Huntly) Basin. Together, they form one of the most important agricultural areas in New Zealand.

These sediments are pumiceous, comprising ash, pumice and debris ejected from the TVZ and deposited downstream from the Pliocene onwards, often by the ancestral Waikato River during its meanderings. Termed the Tauranga Group, they continue to build to this day, in the Holocene, and may be divided into several 'formations'.

So much material was exploded out that the Hamilton Basin became covered both by welded ignimbrite, where the ejected material (carried along by a ground-hugging, fast-

top **Hinuera Formation cliffs (Pleistocene Tauranga Group alluvium) on the shores of Lake Arapuni, one of the Waikato River's hydro lakes upstream of the Hamilton Basin, showing sands and gravels dominated by pumice and ash fragments, with quartz, feldspar and lava crystals, deposited by rivers. Waipa and South Waikato districts.**

middle **The Hamilton Basin, surrounded by a rim of hills. The city of Hamilton is in the centre right, the Hakatarima Range in the foreground, and the Kaimai Range is visible in the distance, on the other side of the Hauraki Plains (the Hapuakohe Range that separates the Hamilton Basin from its neighbour is barely visible between the two). Hamilton City and Waikato District.**

bottom **Puketoka Formation, Mangere, Auckland.**

moving 'pyroclastic cloud') was sufficiently thick to retain enough heat to stick it together, and by pumice and ash alluvium eroded from them (the Puketoka Formation). After several further cycles of alluvium deposition and erosion (the Karapiro Formation), those deposits that held together better formed the little hills visible between Otorohanga and Taupiri; large ignimbrite plateaux (the Mamaku and Tokoroa plateaux) are present to the east of the Hamilton Basin, closer to the TVZ.

The Puketoka Formation, which dates from the Late Pliocene and Early Pleistocene, is also widespread around the Waitemata and Manukau harbours. It underlies the Te Atatu and Avondale peninsulas and may be found on the southern and eastern shores of the Manukau Harbour (e.g. the low cliffs just west of the Southern Motorway, between Takanini and Papakura). It probably also underlies the Hauraki Plains at depth.

Before about 22 ka, and at other times in the more remote past, the Waikato River went through the Hinuera Gap out to the Hauraki Gulf, and hence did not build the Hamilton Basin during these years but instead built up the Hauraki Plains. However, about 22 ka Lake Taupo breached a large pumice dam, sending a huge load of Oruanui Formation sands, pumice, gravels, ash and more (from Taupo's massive Oruanui eruption 26.5 ka) down the Waikato River to become the Hinuera Formation, present in both the Hamilton Basin and the Hauraki Plains. Whether it was the flood itself that changed the course of the river or this happened some time later is unclear, but certainly in the end this sediment changed the course of the river at Hinuera so that it now runs through the Hamilton Basin instead; for some time the river may have bifurcated at Hinuera (or alternated rapidly between the two locations), sending branches into both the Hauraki and the Hamilton basins.

Initially the Waikato River wandered from place to place across the Hamilton Basin rather than being confined to the one course as it is today, building up shingle beds and river plains in the Hamilton Basin similarly to the braided rivers common in the mountainous parts of the South Island, such as the Rakaia or Taramakau rivers. It spread the sediment out in the form of a fan that smothers most of the pre-existing topography between about Hinuera and Hamilton (hence the name Hinuera Surface), although some sediment was carried to almost every corner of the Hamilton Basin. It also built levee-type ridges along the banks of its various courses, damming off the drainage from other areas (the origin of the larger peatlands), and cut down in other areas; sometimes the sediment it deposited cut off embayments in hills to form basins which filled with water to become the small lakes of the Hamilton Basin, some of which have also filled with peat. Victoria Street, Hamilton's main street, is on an old levee of the Waikato River.

Around 17.6 ka the climate began to warm up from the Pleistocene; forests spread, winds decreased and rainfall increased. The Waikato River, now carrying less sediment, began to cut down through the Hinuera Surface, forming the gorge that Hamilton's bridges arch high above and becoming confined to its current incised course. It left small hills covered with tephra standing over an alluvial surface and traces of its former courses in other parts of the basin (these 'paleochannels' represent the courses of the river just before it settled on its final, current course). The gorge within which the river now lies is deeper at the thick, top end of the sediment fan, near Cambridge, and flattens out at the northern end of the Hamilton Basin.

Further sediment has been deposited since, particularly after the most recent

below **The current incised and fixed course of the Waikato River, Hamilton City. Members of my family are walking along a low terrace deposited within the gorge of the river by debris following the most recent Taupo eruption.**

Taupo eruption (1.8 ka). This deposited Taupo Formation pumice sands, silts and gravels in this trench as well as in some streams between Te Kuiti and Taumarunui and in the Whanganui River valley. In the Lower Waikato Basin, the levees built up by the debris from this eruption blocked the drainage of tributary channels and led to the formation (or modification into their current form) of the large lakes typical of that area, such as Lakes Waikare and Whangape (see Chapter 8). The Taupo Formation is the latest member of the Tauranga Group.

VOLCANOES OF THE QUATERNARY

While sediment has given us our beautiful beaches and fertile plains, the most spectacular feature of the north in this, our most recent age, must surely be the volcanoes. Furthermore, they are recent and the TVZ and Auckland Volcanic Field are considered active.

THE VOLCANOES OF THE WAIKATO

The last of the Coromandel volcanoes stopped erupting about 1.5 Ma, but they were not the last subduction-related volcanoes. In the Waikato there is a line (the Alexandra Volcanic Lineament) of subduction-related volcanoes, including the large, andesitic (although surmounting basaltic) volcanoes Karioi and Pirongia and the smaller, basaltic Kakepuku, Te Kawa and Tokanui volcanoes which erupted between 2.7 and 1.8 Ma; all have been eroded to some extent since. They tend to be relatively basaltic in the west and become more andesitic further east, although this is obviously not true of the larger superstructure of Karioi and Pirongia. This line could represent a tear in the subducting slab of Pacific Plate; it intersects the TVZ at a right-angle, terminating at the Mangakino Caldera of 1.6 Ma, notable as the first of the TVZ's rhyolitic volcanoes. Maungatautari is also of a similar age, built up from multiple volcanoes, and also subduction-related, but is not associated with this line; the offshore Gannet Island to the west is different again (possibly associated with the Taranaki Fault) and much younger (0.5 Ma).

SMALL-SCALE BASALTIC SYSTEMS

From the northern Waikato up, there are several areas where the crust is weak; as a result, there have been multiple eruptions of basaltic volcanoes over a relatively short period of time. These are unrelated to subduction (or rifting) but instead occur 'intra-plate', due to a localised source of heat in the lithosphere (the Earth's crust and the upper, solid mantle). This hot-spot is created either by an increased concentration of heat-producing radioactive elements or by a rising asthenosphere plume (the asthenosphere being the hot, viscous layer of the mantle immediately below the lithosphere, typically at least 70–100 km below the surface of continental crust), with usually little alteration occurring in the magma on the way up; hence, the lava produced tends to be basaltic. However, the chemical composition does vary with the size of the eruption; for instance, while the rock erupted from the small Purchas Hill volcano would seem to be mostly from the asthenosphere, the asthenosphere content of the rock erupted from the much larger Rangitoto would seem to have been diluted on the way up by melting in the lithosphere.

Such small-scale basaltic systems include those that erupted between Pukekawa and Drury in South Auckland from 1.6 to 0.5 Ma; one lava flow from this field forms the dam over which the Hunua Falls drop. They form fields of small volcanoes, including scoria cones, basaltic lava flows and explosion craters, each volcano only erupting on one

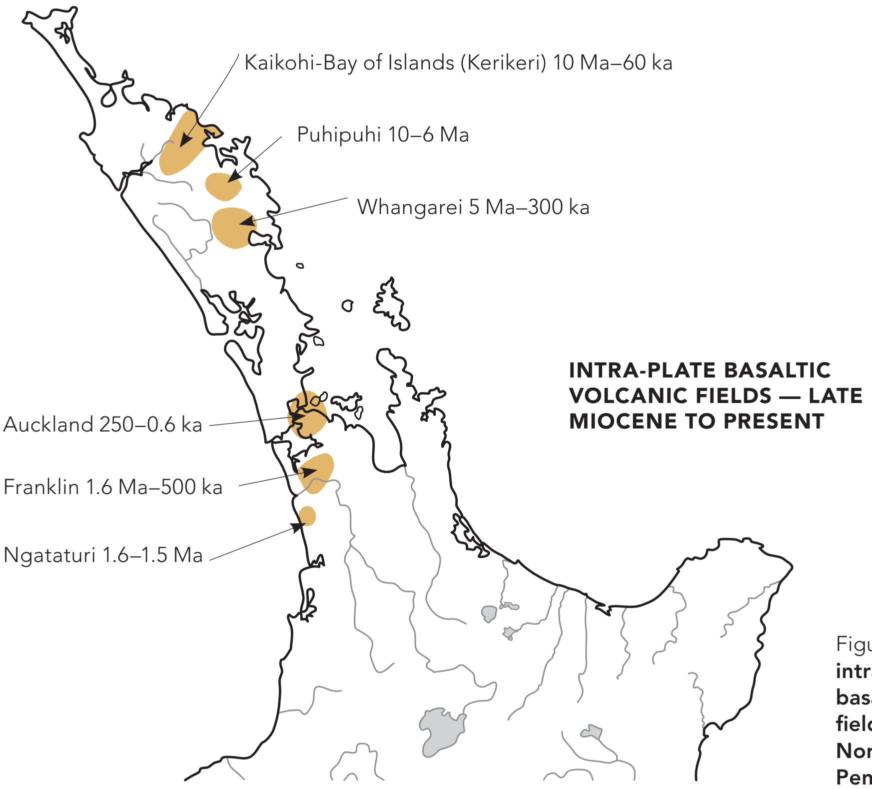


Figure 19 **The intra-plate basaltic volcanic fields of the North Auckland Peninsula.**

occasion. Other such fields (forming the Kerikeri Volcanic Group) that have erupted over the last 10 Ma include those around Kerikeri (the most recent, the Te Puke cones near Waitangi, may be as young as 17 ka) and Whangarei; some near the Waikato coast (the Ngatutura and Okete Volcanic Fields, the latter including the lip over which the Bridal Veil Falls, near Raglan, falls); and of course in Auckland, which started erupting 150 ka. These basaltic cones were found by Maori to make excellent pa sites, both in Auckland and Northland. All have also been used by Europeans, particularly prominently for buildings such as Mt Eden prison and the old stone missionary church at Paihia as well as for purposes such as aggregate (e.g. for roading) and fencing (the stone fences near Whangarei being an example), as has basalt from other basaltic volcanoes in other areas, e.g. Mt Pirongia. Future mining of the scoria cones in Auckland in particular has been vigorously opposed, leading to legislation protecting Auckland's volcanic landscape from quarrying and development as early as 1915.

The Auckland Volcanic Area

The Auckland Volcanic Area is our youngest such field and, depending on your point of view, perhaps the most exciting — it is considered active (given that it has been active for 250 ka and the last volcano, Rangitoto, last erupted about 500 years ago), and another volcano could at any time spell disaster for our largest city; there have been 51 eruptive centres since it started. It is thought that underneath Auckland city, pulses (in the form of a solitary wave, or soliton) of magma have a tendency to ascend through the weak crust and, when they do, give rise to a new volcano; each new pulse ascends in a slightly different place, giving rise to a multitude of small volcanoes rather than one large one. Indeed, it may be

less likely that a new volcano would arise underneath a pre-existing volcano or lava flow because these areas are more solid; the magma may well preferentially emerge through the softer Waitemata Sandstone. We don't quite know what is likely to happen next as the most recent eruption, Rangitoto Island, extruded more lava than all the other eruptions put together and, rather than just erupting once and dying away, it erupted episodically over a period of 1000 years, between 1500 and 500 years ago. This may represent a change in the Auckland Volcanic Field to a more central vent type volcanism, rather than individual, one-off ('monogenetic') events. This is different to the case in the Hawaiian Islands where there is only one hot-spot. The reason for so many islands there is that the Pacific Plate is riding slowly over the hot-spot. Hawaii is the newest island, currently over the hot-spot; the older ones have been eroded down.

As a magma pulse rises it must find a path through the crust, perhaps through a fault or other defect in the crust. When it nears the surface it encounters groundwater and the heat of the magma causes this to flash to steam, causing a violent, explosive eruption of steam, magma and bits of the rock already in place (country rock) which will flatten everything for several kilometres around;

top **Deep inside Sullivan's Cave, a lava tunnel in Three Kings, Auckland. Roots hang down from trees above the roof. These caves were formed as lava cooled and hardened on the outside of the lava flow but stayed molten in the middle; the molten core continued to run, leaving behind a hollow tunnel.**

middle **The explosion crater and tuff ring of Crater Hill, Manukau, Auckland.**

bottom **Auckland — city of volcanoes; a view from Mt Eden's crater rim, looking out over the scoria cones and lava flows of Mt Victoria, North Head and Rangitoto Island. Auckland Domain is yet another volcano; its very small scoria cone is marked by trees on the left of the photograph, between Mt Eden and the wharves; Auckland Museum sits on part of the encircling tuff rim.**

AN AUCKLAND VOLCANO (BASALTIC)

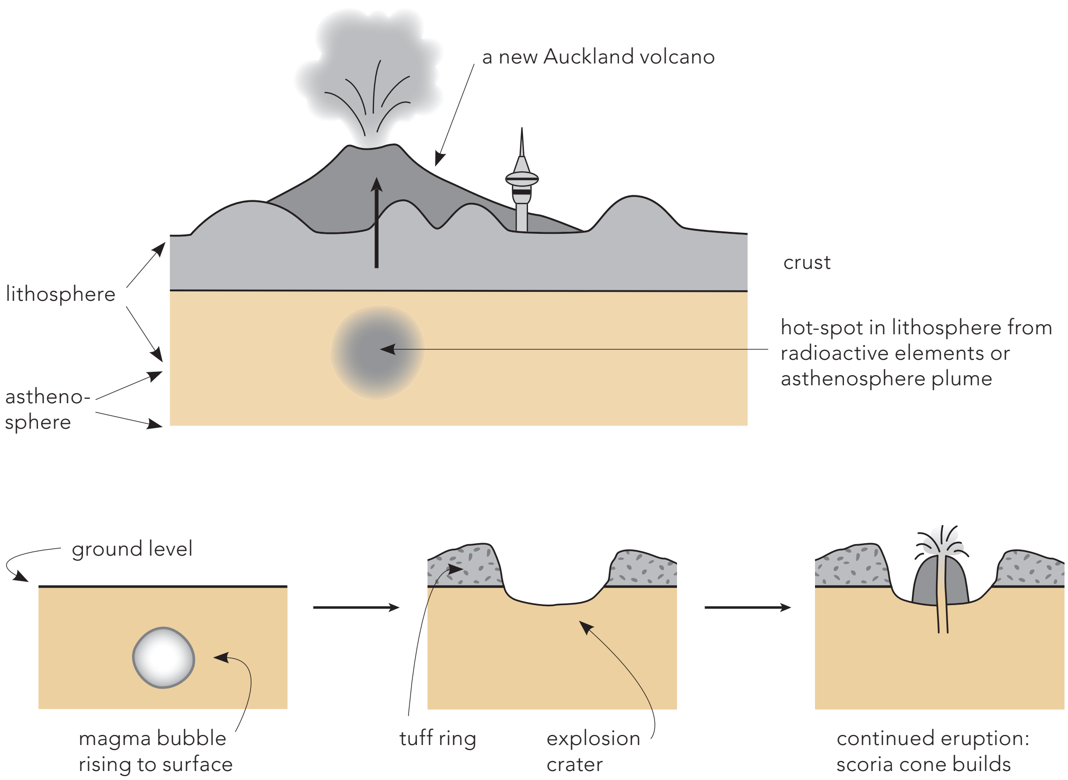


Figure 20 **The evolution of an Auckland volcano. Crustal weakness depressurises the mantle, allowing magma to rise; when it meets the surface, it erupts as a volcano (upper figure). Initially an explosion crater is formed (lower figure), leaving a tuff ring around the outside. Later, if the eruption continues, a scoria cone will be formed in the middle; subsequent lava flows may breach both the cone and the tuff ring, giving rise to the various forms these volcanoes take.**

the exploded material then falls back to the ground as a tuff ring surrounding a crater in the ground, such as one can see surrounding Orakei Basin. After that, basaltic lava, now dry, may continue to fountain out and develop a scoria cone; or the eruption may stop before forming such a cone, leaving just the crater. Later, lava flows can also break through underneath the scoria cone and flow out of valleys, giving rise to structures such as lava caves (for instance, at Wiri) and the burnt forest stumps that dot the rocky shoreline between Takapuna and Milford. Tunnels are often present within the lava flows, formed as the outer lava cools while hot lava inside keeps flowing downhill, leaving a hollow tunnel in its wake.

All the Auckland volcanoes bar Rangitoto have erupted onto dry land as the entire Auckland area was entirely subaerial during the Pleistocene; they probably became extinct after a year or so, again with the exception of Rangitoto. Now, of course, like Rangitoto the next volcano may well start erupting in the sea, and there is an excellent ‘mock-up’ of such an event at the Auckland War Memorial Museum.

The little maar lakes formed in explosion

craters such as the Panmure Basin (now breached in one place by the sea) provide a wonderful record of our recent geological and floral history. They contain ash layers from previous eruptions in Auckland, the TVZ and Mt Taranaki, which we can use to date eruptions; they also contain pollen and other remains of vegetation growing during the Pleistocene and since, allowing us to reconstruct the floral history of Auckland.

Although visibly volcanic and well within sight of downtown Auckland (at least, if one is several floors up), Little Barrier is not an 'Auckland' volcano and neither is it basaltic; rather, it is a dacite-rhyodacite stratovolcano related to subduction which dates from the Late Pliocene and Early Pleistocene.

VOLCANOES OF THE TAUPO VOLCANIC ZONE

Subduction-related andesitic and rhyolitic volcanoes are now only active in the TVZ; activity shifted to its present location about 2 Ma and continues to the present day. The oldest volcanoes are on the western edge of the Taupo Rift (the andesitic stratovolcanoes of Pureora and Titiraupenga) and the youngest on the east (e.g. Mounts Edgecumbe and Tauhara).

As already mentioned, the TVZ forms one of two rifts where the crust under the North Island is being stretched apart, and represents the southern terminus of the Havre Trough and the Lau-Havre-Taupo back-arc basin. This back-arc basin is a stretching of the crust associated with vulcanism located

SUBDUCTION-RELATED VOLCANICS AND A BACK-ARC BASIN

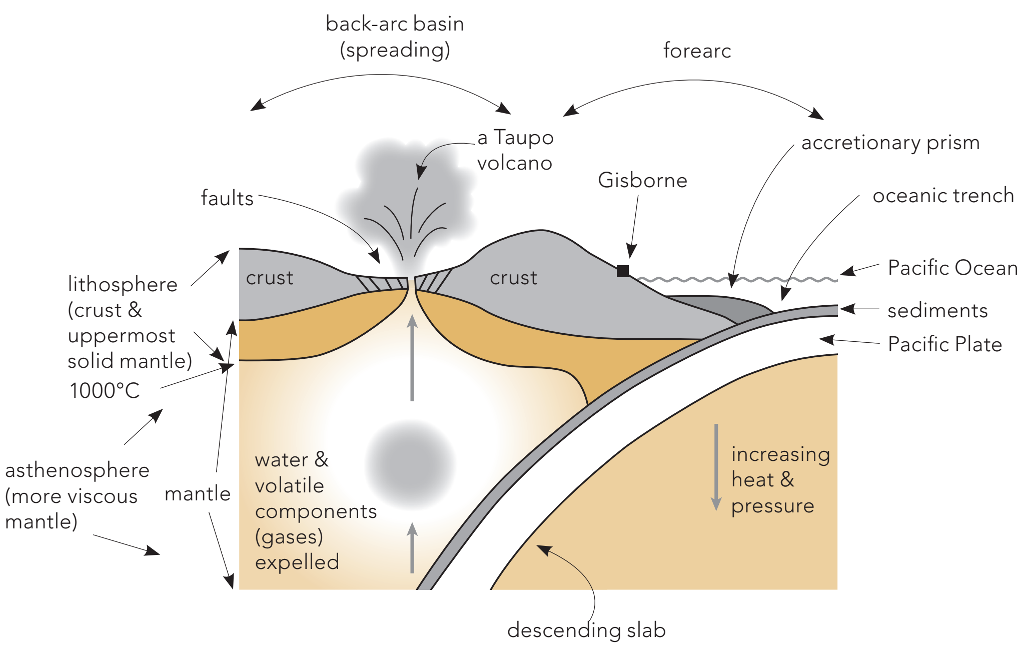


Figure 21 **A cross-section in the vicinity of the Taupo Volcanic Zone (TVZ) and Hikurangi Trench, showing the North Island's portion of the Lau-Havre-Taupo back-arc basin. Note the accretionary prism and forearc basin, similar to that in which our our greywackes were formed in the Palaeozoic and Mesozoic, and the rift forming in the back-arc basin, associated with the TVZ.**

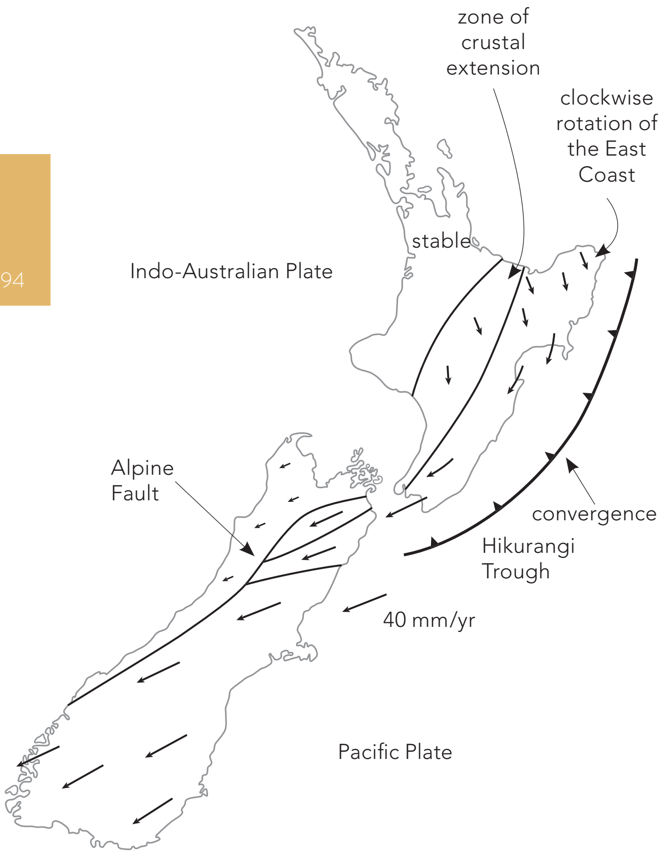


Figure 22 **The Pacific Plate is moving in a southwesterly direction compared with the Indo-Australian Plate, giving rise to not only the Alpine Fault but also changes in northern New Zealand. The direction and length of the arrows represent the direction of motion and the speed relative to a point in Northland, Auckland or the Waikato. Note that Gisborne and the East Cape (the terrestrial portion of the Hikurangi Margin) are rotating in a clockwise direction; it is this that is causing crustal extension, rifting and volcanic activity in the Taupo Volcanic Zone.**

back from the zone of subduction and extends, mostly submarine, all the way up through the Kermadec Islands to Fiji and Tonga (Fig. 16). Volcanism shifted to the TVZ from the Coromandel as the Hikurangi Margin (at the border of the subduction zone, off to our east, and represented on land by the East Cape area and the Gisborne District) rotated clockwise, taking the subduction zone with it (Fig. 22). At sea to our north this caused the Colville Ridge (and the Lau Ridge of Fiji), the seaward extension of the Coromandel Volcanic Zone, to be split by the Havre Trough about 5 Ma, in the Late Miocene. As this trough (and its land equivalent the TVZ) widened and subsided, the Colville Ridge and Coromandel volcanics became extinct and the Kermadec Ridge and TVZ (and, to their north, the Tofua Ridge of Tonga) further east began erupting.

This subsidence is not always apparent to the casual observer, however, because while the rifting and subsidence has been taking place volcanoes have also been ejecting their contents over the lowering landmass and filling in the trough with up to 3.5 km of mostly volcanic debris. Although the initial eruptions were andesitic, the largest eruptions in this zone have been of the more siliceous rhyolite. Massive ignimbrites and ashen rain have also covered both this area and the surrounding greywacke ranges every 1000 years for the last 61,000 years, as well as at less-well-known frequencies before that; the TVZ has produced more than one massive gas-driven and thus explosive (silicic) eruption, resulting in a huge caldera — a volcano that has discharged so much material that the magma reservoir beneath it has partially emptied, allowing the overlying crust to collapse downwards to form the shape of a bowl. Such volcanoes probably first started erupting at Mangakino and have subsequently erupted in multiple locations including Kapenga, Whakamaru, Rotorua, Reporoa and Maroa. The Mangakino Volcanic Centre contributed the major land-forming ignimbrites of the Waikato, the Pakaumanu Group, dating from 1.68 to 1.0 Ma. Major uplift and erosion of valleys took place between the emplacement of the Pakaumanu Group and the next most voluminous ignimbrites, those of the Whakamaru Group of around 0.32 to 0.34 Ma, which coat the area to the west and

top **The Rotorua Caldera, filled by the lake and with the rhyolitic dome of Mokoia Island in the middle. Rotorua District.**

bottom **Ignimbrite cliffs backing the Bay of Plenty coastline west of Edgecumbe; non-welded, rhyolitic ignimbrite of the Rotoiti Formation (Okataina Group). Whakatane District.**

east of the TVZ are probably the product of multiple volcanic eruptive phases, especially in the Taupo–Maroa area. There was, therefore, a considerable period during which caldera activity halted. Rotorua itself exploded 220 ka, ejecting enormous amounts of gas and rock over the landscape and leaving the hollow at the centre of the caldera to be filled in with the lake of the same name, with the rim around the edge of the caldera forming the higher ground that surrounds Lake Rotorua such as, on the west, the Mamaku Plateau. Later vents have given risen to the volcanic domes of Mt Ngongotaha and Mokoia Island.

The two remaining active calderas are the Okataina and Taupo volcanic centres. Okataina has been overtopped, like Rotorua, by rhyolitic domes, in this case Mt Tarawera, which most recently erupted more basalt on 10 June 1886, destroying the famous Pink and White Terraces and burying a nearby Maori village.

All these eruptions and flows of ignimbrite have smoothed over much of the central North Island, from the basins of the Waikato to Te Urewera and the Bay of Plenty; in many places close to the action, vast areas have been buried in ash from pyroclastic flows and tephra — including other volcanoes! Even at faraway Farm Cove at Pakuranga in Auckland there is a cliff of rhyolitic ignimbrite 3 m thick from the Mangakino eruption which occurred near Taupo about 1 Ma. This Kidnappers Ignimbrite can also be found on the east coast from Gisborne south to Cape Kidnappers and as far west as the western Waikato coastline, and was derived from a hot pyroclastic flow of ash that arrived in Auckland less than an hour after the eruption! Volcanic tephra has also been deposited in the last few hundreds of thousands of years on the equally distant Gisborne District coast, in places metres deep. In many areas that have avoided being swallowed by such large deposits, the upper layer of the ground, the soil, is still derived primarily from volcanic tephra from all these eruptions. On road cuttings and other vertical sections one can see an obvious sequence, with different layers representing flows from different calderas at different times.

Most of the surface of the Tokoroa and Kaingaroa plateaux, as well as in the vicinity

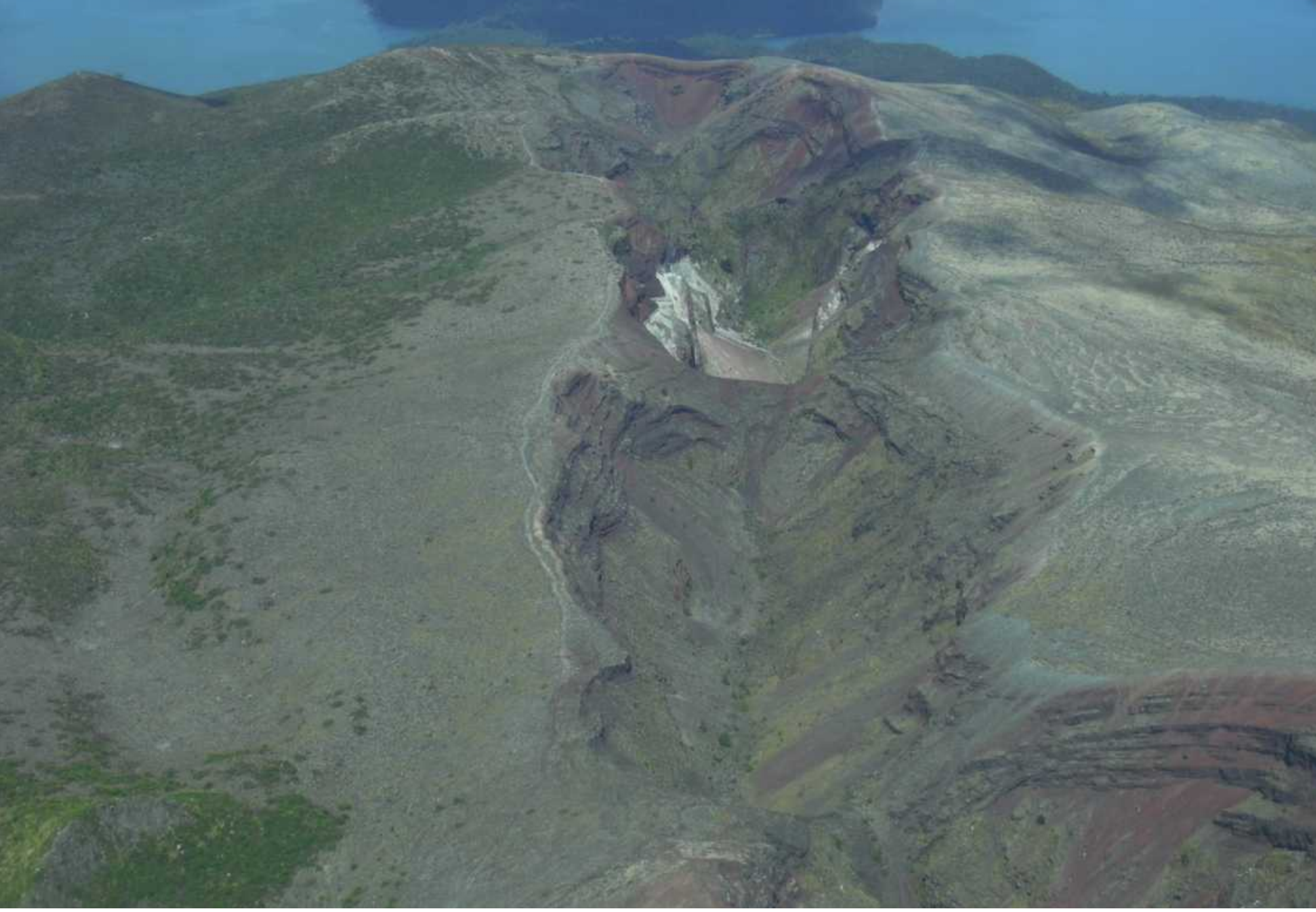
top **Non-welded ignimbrite from the Taupo Volcanic Zone smothers the basement Kaweka terrane. At a road cutting on State Highway 5, the Napier–Taupo Road, Taupo District.**

middle **The flat plain of the Kaingaroa Plateau, covered in pine plantations and underlain predominantly by ignimbrite and traversed by streams incised into it, ends in the distance at the foot of the Ikawhenua Range.**

bottom **Layers of tephra from successive eruptions are exposed in this section near Roturua International Airport, Te Ngae Road, Rotorua District.**

of the Pureora Forest Park, are ignimbrites of the Whakamaru Group, from a flare-up of large eruptions particularly between 320–340 ka, which is variably welded and crystal-rich with some greywacke and ignimbrite fragments (clasts) within. The welded ignimbrite often has well-developed columnar jointing. Some of the western Kaingaroa Plateau is covered in ignimbrite of the same name, non-welded at the base but more welded and with columnar jointing higher up. The Mamaku Plateau west of Rotorua is mostly covered by Mamaku Plateau Formation ignimbrite, pink to purple-grey and variably welded. Many other ignimbrites and volcanic rocks are present all over the TVZ. So much material has been exploded out that the Hamilton Basin is covered both by welded ignimbrite and by pumice and ash eroded away from flows that did not weld together as much; this has given rise to the little hills between Otorohanga and Taupiri, as mentioned previously. All this overlies the Torlesse basement and Te Kuiti Group rocks of the Hamilton Basin, which is downfaulted to the east of the Murihiku rocks of the west coast.

Taupo is the largest caldera still active and has been erupting on and off for 300,000 years, throwing ash as far as Wellington; rhyolitic lavas have made domes that form some of the hills and ridges around Lake Taupo, including the Ben Lomond Dome. Much of the rest of the landscape, especially to the north of Taupo, is covered by ignimbrite and ash fall of the Oruanui Formation (from Taupo's Oruanui eruption, around 26.5 ka, the largest eruption in the last 70,000 years worldwide), which may be kilometres thick in places. The tephra from this eruption originally covered much of New Zealand; in our area, it was eroded and redeposited by the Waikato River to become the Hinuera Formation of the Waikato River catchment and Hauraki Plains, as previously described.



above **The rift that opened in 1886, at the top of Mt Tarawera, Taupo District.**

Although there have since been many eruptions of Taupo, most have not left particularly thick deposits. The most recent, the Taupo or Hatepe eruption of AD233 (a culmination of preceding small eruptions), has left us with the Taupo Pumice Formation, valley-ponded ignimbrite, tens of metres thick, from Ngakuru to south of the lake and almost as far west as Te Kuiti and Taumarunui, especially in the Waikato and Whanganui river valleys. Pumice from this source is mined near Horotiu and used as an abrasive, a filtering agent, in fire-resistant wallboard and lightweight concrete blocks, as a drainage material and as a planting medium in horticulture. Given that it has erupted 28 times in the last 27,000 years, Taupo would seem to be overdue for another eruption!

Mention must also be made of the volcanoes of Tongariro National Park, at the southern end of the TVZ, although these are outside the confines of my definition of northern New Zealand. These are andesitic as opposed to rhyolitic, containing relatively less silica (this trend towards andesite as one travels south is notable in the TVZ; for instance, Taupo's lavas are richer in iron- and magnesium-bearing minerals than are Rotorua's). Tongariro, the oldest of these andesitic volcanoes, started erupting at least 270 ka. Beyond Mt Ruapehu, however, the active volcanic zone ceases, probably because the crust is thicker (about 10 km deep).

Mount Tarawera

Mount Tarawera, which erupted last in 1886, is the only historically active volcano from the central TVZ. A 17 km dike system underneath the mountain and neighbouring Lake

Rotomahana led to eruptions from multiple vents and laying down of the Tarawera Formation of black or red scoria on the summit rift, containing plagioclase, olivine and pyroxene, as well as lake-bed mud around the lake. In the process, it buried the Pink and White Terraces.

White Island

The only volcano erupting on a more-or-less continuous basis in northern New Zealand is White Island; luckily, therefore, it is out to sea and the prevailing winds tend to take its products away from our coastline. A stratovolcano, it has erupted both andesitic and dacitic lava and ash in the past; sulfur mining was abandoned in 1914 after a lahar killed all 10 workers. The volcano is now constantly monitored; its activity is usually limited to boiling mud and steaming fumaroles. There is also a steaming lake in the crater which was created by major eruptions between 1981 and 1983; smaller eruptions of scoria and ash have occurred since, in 2000 and 2012.

below **White Island in the Bay of Plenty — an active andesitic and dacitic stratovolcano. Whakatane District.**

GEOTHERMAL FIELDS AND SPRINGS

Geothermal fields occur when cool groundwater seeps into the Earth and comes into contact with hotter underground rocks; as a result of becoming hotter, it also becomes less dense and then rises through the colder, denser surface water. Hot springs occur at many places throughout our region; they may be classified as high or low temperature depending on which side of 150°C they lie. The hotter springs are generally caused by magma heating the water deep below the ground, which then, being less viscous and hotter, rises. Water buried deep underground may also be heated non-volcanically, as the Earth's temperature increases by about 25°C for each kilometre of depth (geothermal gradient); it may then escape to the surface through porous rock, such as might exist in the shattered rock fragments of a fault. The presence of even low-temperature hot springs, however, may imply a source of heat in some of these locations.

As hot water rises, cold rainwater percolates downwards to take its place, the whole circuit being a very effective heat exchanger extracting heat from the deep magma, particularly in the TVZ.

Faults can also create pathways for the movement of oil and gas, and the warm waters can carry dissolved minerals such as gold, silver, copper and zinc, which are then deposited in the faults as hydrothermal deposits; so there is something to gain from having active faults.

COLD MINERAL SPRINGS

Cold mineral springs are very common in the Gisborne District. Carrying water derived from sea water from subducting marine clays along with rainwater, they are often very saline, containing carbon dioxide and methane and capable of forming mud volcanoes — particularly around the time of earthquakes and particularly where gas concentrations are high and the surrounding rock is soft.

LOW-TEMPERATURE GEOTHERMAL FIELDS

Low-temperature geothermal fields mostly just contain hot springs, although there is a soda geyser at Te Aroha. There are numerous such areas and associated hot-pool resorts in the north; in the Gisborne District, Te Puia and Morere Springs are popular. They are insufficiently hot for anything but bathing and are non-volcanic; rather, they arise from water expelled from sedimentary rocks more than 3 km down that travels through permeable rocks (such as, in this case, sandstones) and along faults, being heated by the Earth's geothermal gradient (approximately 25°C per km).

Further north, perhaps one of the most visited bathing sites is found at Waingaro in the Waikato, where relatively low-temperature hot water (55°C) rises through Murihiku sediment that was crushed in previous tectonic movements and is therefore permeable. The hot springs at Te Aroha also occur as water rises through permeable, crushed rock, this time that of the Hauraki

top **Bruce and William Hadden relax in the Kaitoke hot springs, Great Barrier Island, near Auckland.**

bottom **Hot pools, Tokaanu (at the south end of Lake Taupo), surrounded by *Kunzea* species; a high-temperature spring associated with the Taupo Volcanic Zone. Taupo District.**

Fault, and several other similar thermal resorts exist around Auckland, including Waiwera, Parakai and Miranda. Low-temperature springs (between about 20°C and 55°C) can also be found around Tauranga, in the volcanic rhyolite and ignimbrite, as these contain fractures and joints through which water can percolate. The sedimentary rock around Tauranga, in contrast to the volcanic, is relatively impermeable; as a result, groundwater is scarce and so, therefore, are hot springs.

Some hot springs have been less modified for tourism; the hot springs of the Kaitoke Valley on Great Barrier Island remain in their natural state. These again would appear to rise up out of a fracture zone, with perhaps a source of heat deep underneath. Beach hot springs, such as at Hot Water Beach on the Coromandel and the Te Puia Springs on Kawhia Beach, are also popular and untamed by man, at least to any permanent degree.

There are also low-temperature springs at Kamo and near Kaikohe, although the latter may be associated with the high-temperature Ngawha Geothermal Field. The most common use of these springs is for bathing.

HIGH-TEMPERATURE GEOTHERMAL FIELDS

GEOTHERMAL FIELDS OF THE TAUPO VOLCANIC ZONE

The vast majority of our high-temperature geothermal fields, with by far the greatest and hottest concentration of hot springs, occur in the TVZ, such as around Rotorua and in places like Tokaanu. The TVZ contains 80% of all New Zealand's geothermal systems. These high-temperature springs (above 150°C) are heated by magma at depths of 6–8 km, outcropping on the surface where the rock below is more permeable. From them we

derive geothermal electricity generation, and heat used in industry and domestically in Rotorua.

There are many different fields within the TVZ. That with the largest area of surface thermal activity in New Zealand is the Waiotapu Geothermal Field, a major tourist attraction; probably connected to this is the Waimangu-Rotomahana field, with Lake Rotomahana filling the largest crater formed by the 1886 eruption of Mt Tarawera, an area previously occupied by the Pink and White Terraces. However, probably the most famous is the Rotorua Geothermal Field, which contains more than 1200 eothermal features including alkaline chloride springs, hot springs, mud pools, silica terraces and flats, fumaroles, steaming ground and hot lakes. The heat flow from the TVZ is around 4000 MW, the same as New Zealand's entire hydroelectric power generation.

above **The mud pools of Hell's Gate are powered by the Tikitere Geothermal Field, Rotorua District.**

The type of feature generated by the hot water and steam being discharged depends on the temperature and pressure of the water, the minerals and gases dissolved in it, the composition, structure and permeability of the host rock, and the age of the geothermal system. Such features include:

- pools of hot water, some of which may release large quantities of gas as they arrive at the Earth's surface and the pressure falls to atmospheric
- geysers, occurring when a trapped pocket of

above **Geysers at Whakarewarewa, Rotorua District. Photograph: Siobhan Smith.**

groundwater is heated to boiling point under pressure. Large volumes of steam are produced which erupt up and out, carrying water with it. This reduces the pressure and, as a result, more steam is formed until it erupts at the surface as a column of steam and water. The groundwater then reaccumulates to re-start the process. New Zealand is one of only seven countries in the world that has active geysers

- fumaroles (steam vents) and steam-heated ground, formed where water boils underground so that only steam reaches the surface

- boiling mud pools, created in places that have limited hot water but an abundant supply of steam and rock material of a type that breaks down into mud. Hydrogen sulfide gas (giving the rotten egg smell) in the steam reacts with oxygen in the atmosphere to create sulfuric acid. This dissolves the surrounding rock into fine particles of silica and clay that mix with what little water there is to form bubbling mud pools

- silica terraces and flats, such as the Pink and White Terraces, formed over tens of thousands of years as hot, alkaline geothermal waters flow out over the land, cooling and depositing silica, calcium carbonate and other minerals (this deposit is called sinter). Evaporation contributes significantly to sinter formation, elevating the concentration of silica and hence leading to precipitation

- muddy hot pools, formed by local groundwater being heated by steam and gases from buried geothermal waters. Oxidation in the air allows sulfide to form sulfuric acid, which breaks down surrounding ground. Fine silica particles are held in suspension, although there may be some grey or black colouring due to iron sulfide or black sulfur. These acidic pools do not form sinter deposits; if sinter deposits are present, these indicate that this was once a hot alkaline spring which has lost its water supply and is now just heated by steam and gases.

Our geothermal fields are also important for other reasons: they provide a suitable but very uncommon habitat for a wide range of organisms, mainly bacteria and cyanobacteria that have adapted to cope with them; they have helped shape Maori culture and tourism in the areas where they occur; and they can provide a clean, cheap and renewable energy source.

It is this last that is perhaps the greatest threat to the future of our geothermal fields, as even small changes in pressure, water level and composition as well as temperature can damage and even destroy them irrecoverably. Currently we produce 15% of our energy supply from geothermal sources and this percentage is expected to grow, although some areas have been declared protected by local authorities. Nevertheless, we have lost three-quarters of our geysers since the 1950s, including at Wairakei (due to the power station extracting geothermal water) and at Orakei Korako, drowned by the Waikato's Ohakuri Dam. Connections may also exist between one field and another, so development of one for geothermal energy may affect a neighbour; additionally, rubbish, stones and trampling can all damage delicate features such as sinter terraces. Even mud has been removed from active features for use as cosmetics, and mud pools do not regenerate quickly. Finally, of course, nature may destroy or bury its own marvels, especially in such geologically active areas, as happened with the Pink and White Terraces.

One notable success, however, has been the rejuvenation of Rotorua's Whakarewarewa, quite probably the North Island's premier tourist spot, with the closure of many private bores in that city.

NGAWHA GEOTHERMAL FIELD

Much further north, near Kaikohe in Northland, is Ngawha, with boiling springs, hot medicinal baths and boiling mud pools. It is a veritable mini-Rotorua, the only high-temperature geothermal field in New Zealand outside the TVZ, and has the distinction of having the only geothermal power station in Northland. For generations, Maori have taken their sick people, especially those suffering with rheumatism, to Ngawha for the healing that its hot, sulfurous waters hold. Present there, too, are cinnabar deposits, and mineralogists are much interested in the possibilities of their development. The source of heat is thought to be a silicon-rich magma intrusion deep underground. The water is contained in a reservoir within fractured Waipapa terrane, but is prevented from escaping in much volume by a cap of 500 m of Northland Allochthon.

FAULTS AND EARTHQUAKES

The vast majority of earthquakes in New Zealand occur because of our proximity to a plate boundary; northern New Zealand lies entirely on the Indo-Australian Plate, under which the Pacific Plate is subducting; further south in New Zealand this configuration changes so that in the southern South Island the situation is reversed. As the descending Pacific slab reaches depths of 30 km on the East Coast and up to 300 km as it dips more steeply beneath the Bay of Plenty, there is a tensional strain (slab pull) created within this slab. When the strain builds up too much it will release, resulting in cracking of the Earth's crust in the form of faults (in this case, normal faults) and earthquakes. The depth of the earthquake will usually approximate the depth that the descending slab has reached in that area. The fault will then 're-lock' and stress will begin to accumulate again. Further west, however, where the Pacific Plate is deeper, there is less of this locking and releasing; instead one gets 'free-slipping' and 'slow earthquakes' rather than sudden sharp jolts, and the earthquake zone changes to a volcanic zone.

Nowhere in New Zealand is free of the threat of earthquake, caused by rupture of a fault. However, the western Waikato and the North Auckland Peninsula, being furthest from the plate boundary, certainly have a lower risk than areas further east. Indeed, northern Northland is the part of New Zealand at the least risk of an earthquake, with a median return time for an event scored on the Modified Mercalli scale — a measure of intensity, not magnitude — as MM VII (one that causes broken chimneys, cracking of unreinforced stone and brick walls and a few instances of liquefaction) in Kaitaia being about 1200–2000 years. As one goes south, towards the plate boundary which is to the southeast, this interval reduces: Auckland has a return period of somewhere between 260 and 650 years, Hamilton 220 years and Taumarunui 75 years. There is an earthquake belt, where large, damaging earthquakes are liable to occur, about 300 km wide and 20 km deep extending in a generally southwesterly direction from the Bay of Plenty to East Cape, parallel to the plate boundary.

One significant earthquake has hit the west, however, in recorded history: the 1891 Port Waikato earthquake broke chimneys and brick walls as far away as Mercer and Raglan.

Heading east, again towards the plate boundary, the earthquake frequency increases again. Hamilton's 220-year return period for a MM VII event reduces to 97 years for Tauranga, and to 26 years for Whakatane and 27 years for Rotorua. Local geography is, of course, also important; Taupo is not quite so earthquake-prone with a return period of 44 years for an MM VII and Gisborne has been estimated to have a return period of 59 years; by comparison, Wellington's return period for such an earthquake is 42 years.

Gisborne was the closest city to an offshore earthquake of magnitude 6.8 on 20 December 2007, which led to the collapse of three buildings there as well as $16 million of insurance claims.

Unfortunately, due to the 2010 and 2011 earthquakes in Christchurch, many of us have a good idea of the sort of damage that earthquakes can cause. In earthquakes scored as over MM VI, those areas that contain waterlogged, fine-grained sands, such as recent (Quaternary) alluvial plains, can liquefy, with associated land subsidence, sand boils, ground fissuring and lateral spreading as the water comes out of these soils onto the surface, along with piles of mud. Landslides may also occur on hilly terrain.

No known active faults occur on land in the west Waikato, although to the west the offshore Turi Fault may pose a risk. The westernmost active onshore Waikato fault is the Kerepehi Fault in the Hauraki Plains. Nearer Auckland, the Wairoa Fault forming the western side of the Hunuas is considered active and the

opposite **A fault visible from a distance; the gully on the other side of the ridge between two domed ends of Whale Island is, in fact, a fault. Whakatane District.**

right **The Galatea Basin, a fault-bounded depression at the edge of the Kaingaroa Plateau (to the right) and bordered to the east by the Ikawhenua Range. Whakatane District.**

FAULTS AND VISIBLE CALDERA OF THE UPPER NORTH ISLAND

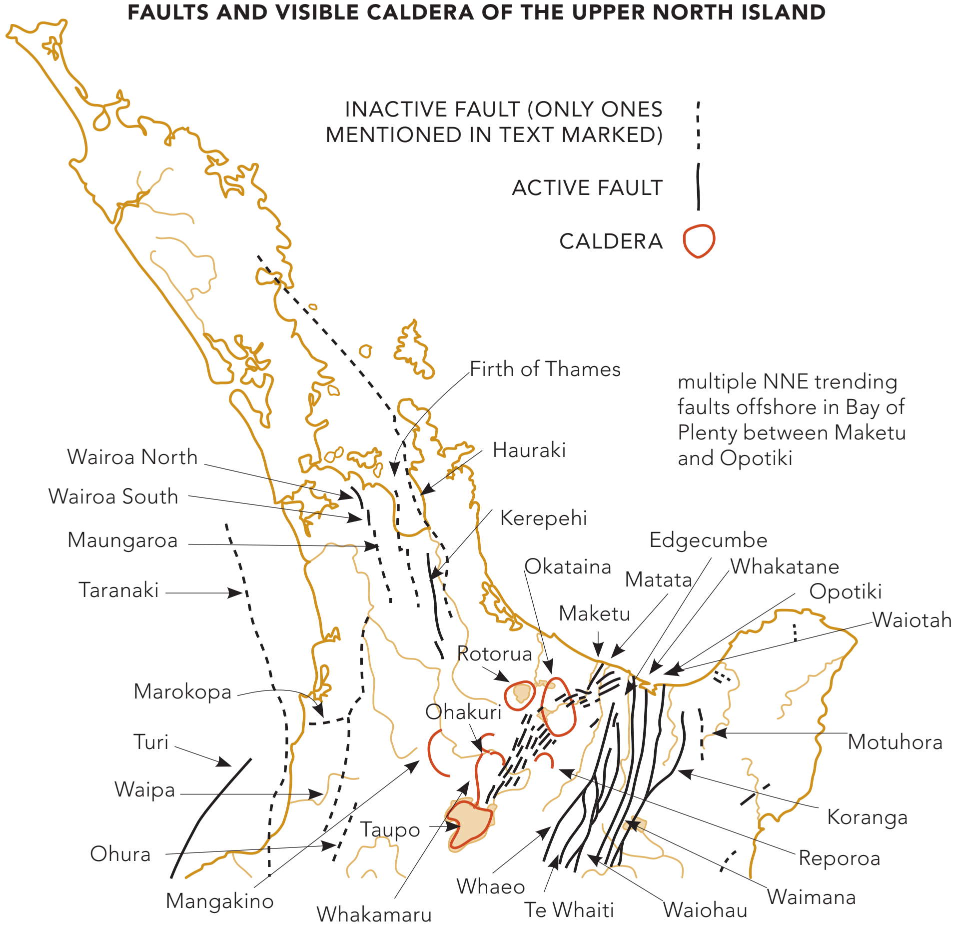


Figure 24 **The fault lines of northern New Zealand. Active faults are shown as solid lines. Representative inactive faults, including some mentioned in the text, are shown as dotted lines. Calderas of the Taupo Volcanic Zone (TVZ) are also outlined, where marked by topography. Note the concentration of faults in the TVZ as well as in the axial ranges, especially in the area of Te Urewera. Scattered active faults are present throughout the rest of the axial ranges, with only three in the west — the offshore Turi, the Kerepehi (underlying the Hauraki Plains) and the Wairoa (on the eastern boundary of the Auckland urban area).**

Drury Fault, lifting the hills east of Papakura, may also be a source of risk. These faults all relate to block faulting in the Hauraki Graben, as that rift gradually increases and the Hauraki Plains fall down into it; the Kerepehi Fault will probably move approximately every 2500 years. There are no active faults onshore north of the Manukau/Hunua region, although perhaps that is little consolation to Aucklanders given that the Wairoa Fault, at its northern extremity between Clevedon and Whitford, is only about 25 km from the city centre. At least there are no faults considered to be active in one of Aucklanders' favourite hangouts, the Coromandel Peninsula!

There are also some inactive north–south faults, such as the Waipa Fault, in the west, as well as transfer faults associated with these heading off east and west, such as the Marokopa Fault, that probably emerged during crustal stretching when what became New Zealand drifted free of Gondwana all those millions of years ago.

Earthquakes also tend to be shallower further east, as the Pacific Plate has not attained as great a depth closer to its point of subduction, marked by the offshore Hikurangi Trench to our east. Thanks to this plate boundary, as one goes further east the continental crust becomes more and more deformed; indeed, the entire eastern North Island east of the Wellington-Whakatane Fault Zone is detached from the rest of the continental rocks of the Indo-Australian Plate (Peter Bird used the term 'Kermadec Plate' for this area). There are large numbers

left **A waterfall drops over greywacke at the edge of the Drury Fault, Te Maketu Historic Reserve, Auckland, where a vertical displacement has taken place.**

right **Railway lines buckled by the force of the 6.1 magnitude Edgecumbe earthquake of 2 March 1987. Whakatane District. Photograph: Lloyd Homes, GNS Science.**

of active faults, trending east-northeast, in the TVZ, including recently active ones such as the Edgecumbe Fault at its eastern edge, which caused the Edgecumbe earthquake of 1987. Many of these faults have given rise to the ridges and valleys of Te Urewera which extend from the divide northwards to the eastern Bay of Plenty coast, hence the north–south orientation of these ranges. In the Gisborne District there are also many faults, predominantly aligned southwest to northeast although some are orientated at right-angles to the ridgeline.

Tsunamis may approach us, from either local or distant earthquakes, but the earthquake must occur at sea; one in the Tonga–Kermadec area would take 4 hours to get here, and one in Chile about 16 hours. The largest tsunami that we have evidence of may have reached a height of 30 m at landfall; it was caused by the eruption of the Healy Caldera (275 km east-northeast of Whangarei) 600 years ago. Evidence for it exists in Northland and Great Barrier Island. The city of Whangarei itself is considered vulnerable to a tsunami despite being quite far inland at the head of a harbour.

LANDSLIDES AND EROSION

Landslides are common in Northland, especially where strong, permeable igneous rocks (in particular the Tangihua Complex) overlie the weaker Tertiary sedimentary rocks of the Northland Allochthon and Early Miocene (and similarly with the East Coast Allochthon), as well as on the slopes of eroded stratovolcanoes (e.g. Bream Head). Permeability is important because more-permeable rocks allow water to seep beneath the overlying strata and into weaker beds underneath, destabilising it; most landslides occur when soils become waterlogged, such as when there has been heavy rain.

Similar weak mudstones, such as those of the Mangakotuku Formation and Mahoenui Group in the Waikato, also pose slip risks, as do the old dune sands of the Awhitu Group.

The Te Kuiti rocks tend not to be as susceptible to landslides, and around Auckland the Waitemata Group rocks are also generally stable away from cliffs, although they are often intensely weathered to a depth of about 20 m and there is considerable variation in their strength. The cliffs, however, are subject to erosion and a danger to property. The greywacke basement rocks form prominent erosion-resistant features such as headlands, as do, in general, igneous rocks, with unconsolidated ash being a prominent exception.

East Cape's allochthonous rocks are as prone to landslides as Northland's; its more recent mudstones in particular are even more erosion-prone, a situation compounded by deforestation and consequent loss of the stability that the forest cover provided. Te Puia township is located on an active landslide, moving at around 55 mm/year towards the coast; this sliding slab of Late Cretaceous rock may be lubricated by water from the local springs.

Landslides are responsible for our second largest lake, Lake Waikaremoana, as well as the neighbouring Lake Waikareiti, by blocking off their respective outflows.

top **A bridge washout after heavy rain, near Te Kao, Far North District.**

top middle **An attempt to protect against erosion. Wainui Beach, Gisborne District.**

bottom middle **Pine plantations cover the hills of the Gisborne District in an attempt to limit erosion.**

bottom **The sandstone blocks of the Tuai landslide that blocked the Waikare River, forming Lake Waikaremoana in Te Urewera, Wairoa District.**

TAURANGA HARBOUR

Tauranga Harbour, the extensive but shallow harbour on the shores of which stands northern New Zealand's third largest city as well as one of New Zealand's most important ports, is an example of a landform created by all the various mechanisms that have operated in the Late Tertiary and the Quaternary, as it is the product of volcanic activity, tectonic movements and the deposition of sand. The volcanoes of the Kaimai Range, 5 million years old, flank the harbour to the west and underlie much of the rest of the region; around the same time, the rhyolitic (viscous lava) domes of Mt Maunganui, Bowentown and Minden that surround the harbour were also formed. After a period of quiescence, pyroclastic explosions ejected hot pumice and ash clouds which turned into ignimbrite, coating much of the land around. Then, about 1 Ma, the Kaimai Range was uplifted and the Tauranga area subsided to form the basin we know today.

More-recent volcanic activity has also contributed to the topography, including the Rotorua eruptions which spewed yet more ignimbrite flows across the district, most recently 200 ka, as well as an ash covering derived from both Rotorua and Taupo.

At the height of the last glacial, around 20 ka, one could have walked to Mayor Island from the mainland because of the lower sea levels. As the sea rose again to its present level (since about 6500 years ago), the valleys of the rivers that flowed across the harbour area became both filled with sand and drowned by the rising waters, producing the very indented inner coastline. Since then, sand has built up around the domes of Bowentown and Mt Maunganui/Mauao to form Matakana Island as well as the surf beach we know today as 'the Mount'.

below **Tauranga Harbour lies behind the sandy Matakana Island, anchored at its southern end by Mt Maunganui/Mauao, from the side of which this photograph is taken. Western Bay of Plenty District and Tauranga City.**

GEOLOGICAL LEGEND

VOLCANIC AND ASSOCIATED INTRUSIVE ROCKS			SEDIMENTARY ROCKS		
Rhyolite and dacite of domes and flows;associated pumice and tuff. Andesite and basalt of volcanoes, scoria cones and flows; agglomerate and breccia in central and northern North Island.	Qv	Q	Marine, estuarine and coastal lagoonal deposits. Dune sand, swamp deposits, peat and lake silt. Aggradation (mainly glacial) gravel and till.	LATE QUATERNARY	CENOZOIC
		Ql	Lahar deposits in Taranaki and central North Island.		
Rhyolite, andesite and basalt of dissected domes and flows; associated pumice and scoria. Ignimbrite and tuff, rhyolitic to dacitic, in central and northern North Island.	Ꝗv	Ꝗ	Marine gravel, sand, silt, conglomerate and coquina limestone. Alluvial sand and gravel of high inland terraces. Aggradation gravel and local glacial deposits.	EARLY QUATERNARY	
Rhyolite, dacite and andesite of dissected domes and flows; associated pumice and agglomerate in Northland and Coromandel.	Ᵽv	Ᵽ	Marine sandstone, siltsone, limestone; pumiceous and andesitic tuff. Non-marine conglomerate and sandstone.	PLIOCENE	
Deeply weathered rhyolite, dacite andesite and basalt in Northland; hydrothermally altered pyroclastics.	Mv	M	Mainly sandstone, siltstone and limestone; pumiceous and andesitic tuff. Non-marine conglomerate and coal measures.	MIOCENE	
	Θv	Θ	Mainly limestone and calcareous siltstone, commonly glauconitic; sandstone and siltstone; conglomerate.	OLIGOCENE	
	Ev	E	Bentonitic mudstone, greensand, siliceous claystone and limestone. Quartzose coal measures.	EOCENE PALEOCENE	
Tholeitic basalt, andesite, spilitic lava and minor marine sediments in Northland and East Cape.	KEv				
	Kv	K	Sandstone, siltsone, claystone, greensand, siliceous shale, conglomerate, dark argillite, minor spilitic tuff and lava. Coal measures and conglomerate.	CRETACEOUS	MESOZOIC
	Jv	J	Well-bedded sandstone, mudstone and conglomerate in Waikato. Interbedded greywacke and argillite, with volcanics and chert, in North Island axial ranges and Northland.	JURASSIC	
		T	Well-bedded tuffaceous sandstone, mudstone, tuff and conglomerate in Waikato. Structurally disturbed interbedded grey wacke and argillite in North Island axial ranges and Northland; grades into schist in Southern Alps.	TRIASSIC	

OTHER FEATURES

Lake

Fault

Age ranges are shown by double age codes (e.g. TJ), the colour being that of the older age

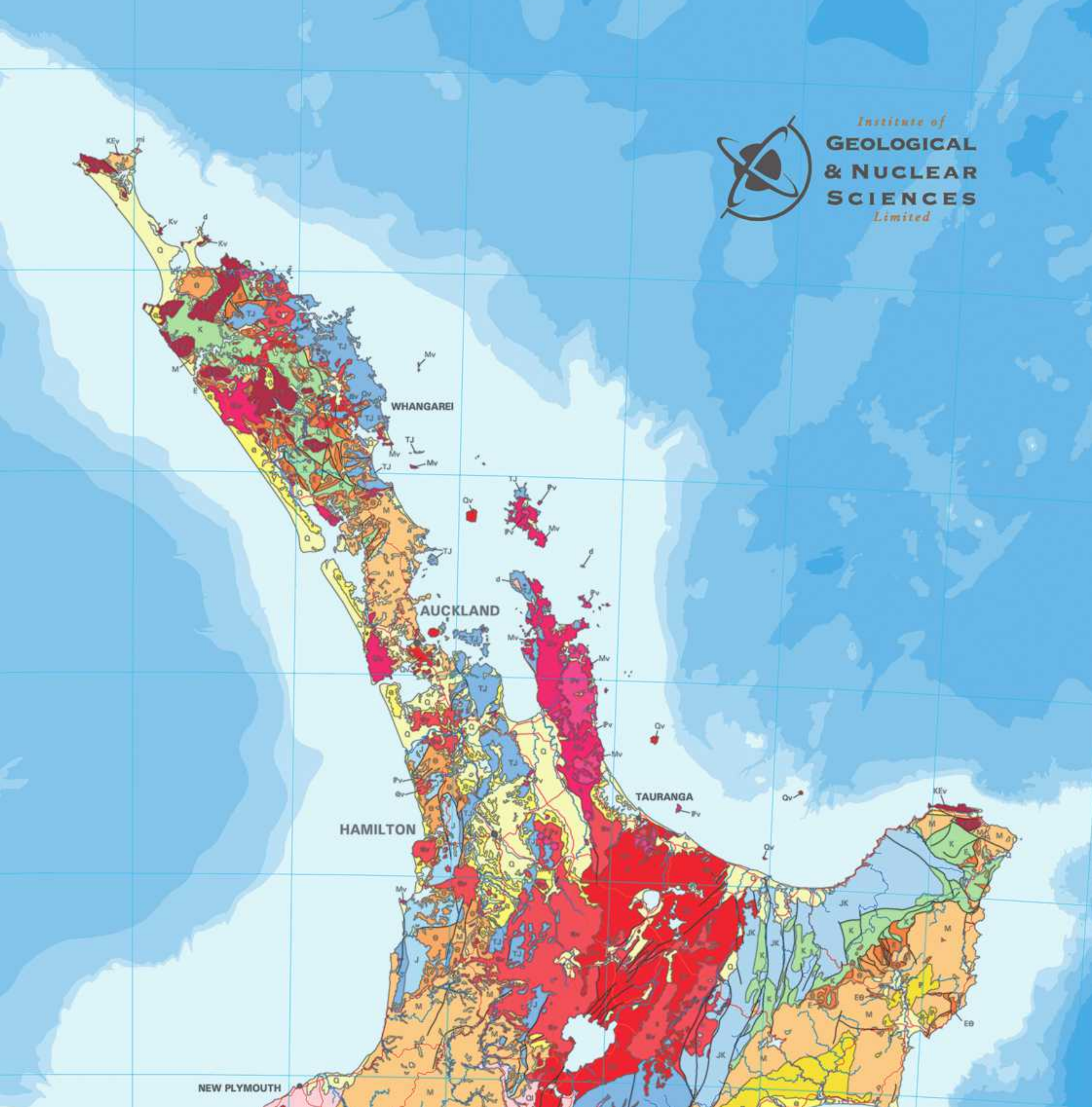


Figure 25 **The geology of the upper North Island, as exposed on the surface (see text for details). Note the older basement rocks in the east and west, smothered by more recent volcanic material in the Taupo Volcanic Zone. Tertiary sediments, most frequently from the Miocene and particularly common north of Auckland, in the King Country and Gisborne District, overlie basement rocks where they have not been eroded away. Older volcanics are dotted around Northland and the Coromandel Peninsula while recent alluvium fills the Waikato basins and forms much of the western coastline and low-lying coastal plains of the east coast. Not mentioned in the legend is 'd', present at the summit of Mt Moehau and on Cuvier Island, which indicates the presence of plutonic diorite and quartz diorite. Map reproduced courtesy of Lloyd Homer, GNS Science.**

CHAPTER TWO:

SOILS

INTRODUCTION

Soils are a natural product formed from rock by the action of living organisms and climate (not only rainfall and temperature, but also rainfall intensity, freezing, seasonal variations, etc.). The local topography (an important factor in shade, shelter, drainage and erosion potential) and the length of time the elements have had to work on the geology to turn it into soil both contribute to soil characteristics. Soil fertility is complicated; physical properties and soil chemistry are both important, as is the biological community of the soil. The most fertile soils, i.e. those that best suit agriculture and horticulture, are typically well drained, well aerated, easily penetrated by plant roots, not too acidic and nutrient rich. Less-fertile soils may be altered to make them more suitable for such purposes; for instance, waterlogged soils can be drained and fertilisers can be used to add nutrients; many soils have been chemically fixed for agricultural and pastoral purposes.

On steep slopes there can be many different soil types over small changes in distance; it is also generally the case that the steeper the slope, the less the soil cover, with bedrock often being exposed on extremely steep slopes such as cliffs and road cuts. On flat and rolling country, soil types change much more slowly.

The type of soil can, in turn, make a great deal of difference to the vegetation. In the Pureora Forest Park in the central North Island, giant podocarps grow on rich volcanic soils; even in the west, where the amount of volcanic debris is less, tawa and thin-barked totara dominate the heights. However, before the Taupo eruption the forest was dominated by tanekaha, kaikawaka (New Zealand cedar), bog pine and giant herbs, growing on quite different, more poorly drained soils. Other factors were undoubtably also important, such as which plant species were able to establish most easily following the eruption.

THE FORMATION OF SOIL

Soil may be formed from both organic and mineral matter; most soils are a mixture, with an organic surface layer (horizon) on top of mineral horizons.

The organic component varies from freshly deposited leaf litter to well-decomposed vegetative matter or, in anaerobic, waterlogged environments, undecomposed peat. Mineral soil material, which by definition contains less than 18% organic carbon, is derived from non-organic matter, including the underlying bedrock, alluvium, loess and volcanic tephra.

Over time, minerals at or near the Earth's surface are subject to 'weathering', which may be both physical and chemical:

- Physical disintegration is the disintegration of bedrock into smaller particles without chemical change, the instruments of which include wind, water, heat and biological agents — such as earthworms which cause 'bioturbation' of the soil and plant roots such as those of pohutukawa, which break apart the cliff rocks to which the tree often clings. Stress within rocks, leading to their disintegration, can be caused by thermal expansion and contraction, salt weathering, freeze–thaw activity, hydration and the release of pressure when rocks previously buried deep underground are exposed to much lower atmospheric pressures.

- Chemical decomposition involves chemical reactions that result in the formation of new minerals. This may occur through reactions with inorganic compounds, such as water; plants and animals can also contribute to chemical weathering, for instance through the production of organic acids. Chemical weathering of silicates, the most common mineral group, occurs mainly by hydrolysis — hydrogen ions (the smallest cation, or positively charged ion) from water enter into the crystalline lattice of the rock and replace the larger cations. Mafic minerals, with iron and magnesium in their structure, are the most easily hydrolysed; quartz, having a dense structure just of silicon and oxygen, excludes hydrogen ions much more effectively and resists weathering. Chemical weathering is important in the creation of clay minerals (see below).

Note that erosion involves movement of rock (e.g. by water), unlike weathering which occurs 'in situ'.

left **Productive Granular Soils near Bombay, Auckland.**

SOIL PARTICLES: CLAY, SILT, SAND AND LOAM

Soil particles come in different sizes. The largest size of particle commonly forming soil is sand, a grain of which has a diameter of up to 2 mm; silt particles are smaller than sand (less than 0.06 mm in diameter). Both represent chemically unchanged minerals. Clay particles are smaller again, less than 2 µm in diameter (according to the definition in the *New Zealand Soil Handbook,* which uses size alone to distinguish clay from silt) and typically chemically changed from the parent material (for some definitions this is a defining characteristic). Between soil particles are voids known as pore spaces, filled by either water or air; a mixture of both is ideal for nourishing soil organisms and plant roots, and in a good pasture soil the ratio of soil particles to air and water may be 50:10:40.

Soils are divided into texture classes according to the size of the particles found therein; for instance, sandy soils contain 80% or more sand and 8% or less clay. There are 11 soil texture classes, defined by the relative proportions of sand, silt and clay particles; those termed loams have a more even concentration of all three particles. Many loams are considered ideal for agriculture and market gardening because they retain more nutrients, humus and moisture than sandy soils, yet drain more freely and are easier to till than clay soils.

Soils that contain a lot of clay generally have numerous small pore spaces between particles, because of clay's finer texture; they therefore retain moisture better although this is not always readily available for plants, being held under high tension. A consequence of such waterlogging, however, is that aeration is often poor. Sandy soils, on the other hand, have larger pores allowing better aeration, but water (and nutrients) can rapidly pass through them and be lost. Clay may sometimes also prove a barrier to plant roots. However, soil characteristics vary between different clay soils; for instance, some can take up relatively large quantities of water (e.g. montmorillonite), hence they shrink and swell with repeated drying and wetting, while others, such as kaolinite, cannot.

Clay particles are a particularly important component of soil, as they have irregularities of charge on their surfaces which keeps other charged nutrients, such as potassium and sulfate ions, held in the soil rather than allowing them to be washed down into deeper layers (leached) by rain; the particles being so small also means that clay has a large reactive surface area. The total amount of surface negative charge in a soil, important contributors to which are clay particles and humus, is called the cation exchange capacity. Clay particles also stick together (they are cohesive), yet clay is plastic (it can be permanently deformed without breaking apart) and, together with organic matter (humus), clay binds soil particles together into aggregates.

Clay itself refers to the naturally occurring material primarily composed of fine-grained minerals, usually plastic when wet but which hardens when dried or fired; phyllosilicates (sheet-forming silicates) are known to have

such properties and clay minerals, which are hydrous aluminium phyllosilicates, formed in the presence of water, impart this property to clay, although clay may also contain other associated minerals and phases. Clay minerals are 'secondary', being formed from the chemical weathering of 'primary' silicates. They can be broken down further, mainly by hydrolysis, into silicate debris and cations (e.g. silicon and aluminium), but usually this latter, radical step only occurs in tropical environments.

Kaolinite ($Al_2Si_2O_5(OH)_4$) is a common clay mineral, produced from chemical weathering of feldspar and other aluminium silicates, and is often found in warm, humid environments. It may be coloured orange-red by haematite in some parts of the world. Rocks rich in kaolinite are called kaolin or china clay. Other clay mineral groups include smectite, illite and chlorite. Smectite clay minerals (such as the aforementioned montmorillonite) are common in the Gisborne District and swell when wet or immersed in water, contributing to the erosion problem in that district. Their presence on Mars is evidence of previous surface water on that planet.

Another compound commonly encountered in clay is the more amorphous allophane, a hydrous aluminium silicate clay mineraloid. As opposed to a true mineral, it does not have crystallinity (it has 'short-range order' but lacks the long-range, well-defined crystalline order of a mineral) and its chemical composition varies beyond what one would accept to define a specific mineral. Allophane (chemical formula $Al_2O_3{\cdot}(SiO_2)1.3–2{\cdot}2.5–3(H_2O)$) is a product of the weathering of volcanic glass and feldspar.

Rocks made of fine particles, such as mudstone and siltstone, often contain significant amounts of clay minerals; indeed, all sedimentary rocks contain some clay minerals, and bits of organic matter are commonly found in clay.

As well as being an important component of soil, clay is also used in the manufacture of pottery.

right **Red clay (Orthic Brown Soil) in our most 'tropical' locality, Te Paki Farm Park, Far North District.**

SOIL COMPONENTS

SOIL HORIZONS

The various layers of soil are named horizons, not all of which are necessarily present in every soil; many soils consist of a very superficial, dark organic horizon followed by mineral horizons. The following description is based on the horizons described by JDG Milne.

Organic soil material may be divided into a peaty O horizon, composed of organic material accumulated under wet conditions, and the drier L (fresh leaf litter), F (partly decomposed) and H (decomposed sufficiently for original plant material not to be recognisable) horizons. In some texts, one may see the term 'O horizon' used for any organic horizon. These soils are dark brown or black due to the amount of carbon they contain.

The uppermost mineral horizon is the A horizon, or topsoil. It contains a lot of organic matter and more biological activity than deeper horizons. It is usually relatively leached of more soluble constituents, including iron, aluminium, organic compounds and clay (leaching refers to the process by which water-soluble plant nutrients are carried by water

above **Well-developed horizons in Hamilton Ash (see 'Granular Soils') to the southeast of Lake Waikare, Waikato District (at Tahuna Road just north of its intersection with Rutherford Road). Note the dark, superficial organic layer, followed by the A horizon and a deeper, leached E horizon. Underneath this is a redder B horizon and, at the very bottom of the cutting, is the C horizon of unconsolidated rock.**

from more superficial layers down to deeper layers, or out of the soil altogether). Soils become more leached the older they are and the more pluvial the climate; leaching occurs in any soil where there is even a temporary excess of water over the amount the soil can absorb. In a strongly leached soil, particularly one developed under forest cover as ours predominantly were, at the bottom of the A horizon one might often find an E (eluviated) horizon. This is a pale level where organic compounds, clay, iron or aluminium have leached out to such an extent that left behind there is a white layer dominated by pale silicates but lacking in essential nutrients, as the roots of long-lived trees add little organic matter back into the soil year by year, unlike grasslands; hence, most of the organic layer of forest soils comes from the litter layer and is concentrated in just the top part of the A horizon.

Next is the B horizon, the subsoil; composed of minerals without rock structure, it accumulates those products leached from the A horizon, with the iron oxides and clay often giving it a brighter colour than the horizons above or below. The clay content of most B horizons increases with time, coming both from weathering of the B horizon minerals and from deposition from the A horizon.

Together the A and B horizons comprise the solum, or true soil.

Deeper down is the soil parent material, the C horizon, unconsolidated rock (boulders that can be scraped away by hand) little affected by weathering and with little biological activity. The C horizon lies on top of the R horizon, of partially weathered but continuous bedrock.

Some soils are buried under other soils, for instance, by volcanic eruptions (buried paleosols); the term 'paleosol' can also refer to soils formed a long time ago under environmental conditions that bear no relations to those of the present, yet have never been buried (relict paleosols), and to those that were buried but have since been stripped of their previous covering (exhumed paleosols).

FLORA AND FAUNA OF THE SOIL

While plants produce organic matter from inorganic components, animals and micro-organisms living in the soil gradually transform decaying plant litter into organic humus, recycling the nutrients back into the system. By weight, often more such organisms live below ground than above. Soil communities are quite different under forest cover than under pasture, as the latter has more-even, shallow roots and a relatively homogeneous nature.

Most animals in a forest's leaf litter are small and nocturnal, enjoying the consistently cool, moist and dark environment that the leaf litter and soil provides. The largest include native cockroaches, weta and slaters, which chew large plant material into smaller pieces for smaller organisms such as microbes to act on. Some animals, such as cicada nymphs, derive their nutrition from sucking and eating live roots, while weta may eat living plant leaves, and a multitude of creatures feed on dead plant material, micro-organisms and dung, including amphipods, isopods, native earthworms and millipedes; fungi and bacteria (especially the fungal-like bacteria actinomycetes, which gives an earthy smell) are also found in soil, and free-living nematodes, most less than 1 mm long, are also very common. Some animals are predators — such as peripatus, beetles, mites and centipedes — while snails and slugs will devour almost anything organic and some larger ones are carnivorous into the bargain!

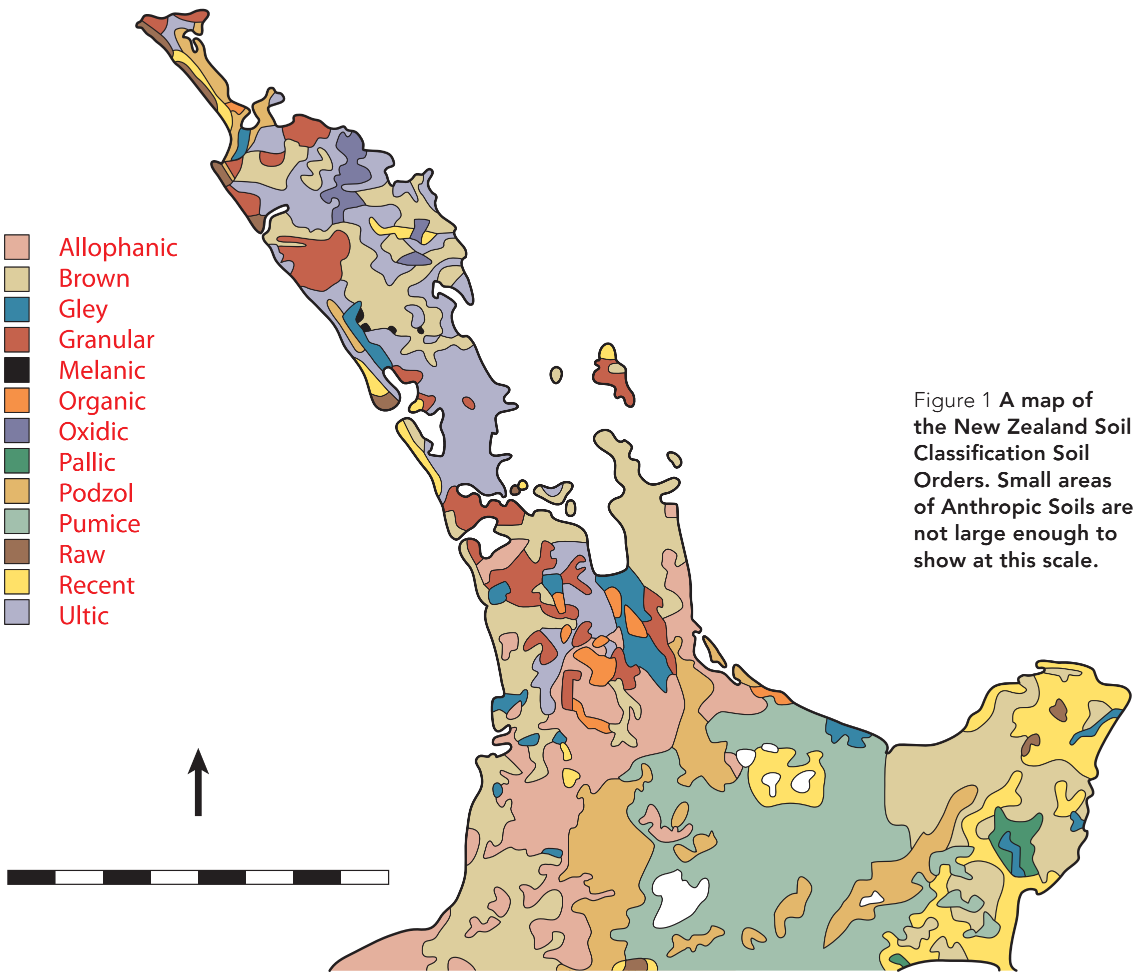


Figure 1 **A map of the New Zealand Soil Classification Soil Orders. Small areas of Anthropic Soils are not large enough to show at this scale.**

Bacteria are the most numerous organisms in soil, and their oxygen demands may create anaerobic conditions in poorly aerated, waterlogged soil; protozoa such as amoebae may in turn feed on bacteria. Single-celled algae are also common microbes, especially near the surface, since they use sunlight as their energy source. Some microbes fix nitrogen on the roots of plants, thereby enriching the soil and helping the plant (symbiosis), and some (such as the *Cordyceps* fungus) may parasitise other inhabitants.

Generally, the humus that develops under beech trees and both native and introduced conifers is 'mor' humus. It is typically fibrous, slow to decompose and acidic; most of the organic matter from the trees eventually falls into the litter layer where it produces organic acids as it decomposes, increasing mineral weathering and the leaching effects of water percolating through the soil. The L, F and H horizons described above may often be easily seen. Fungi tend to predominate in forest soils, especially those producing mor soils, as they are more tolerant of acidity than bacteria and actinomycetes. Soils formed from peat, where decay takes place only very slowly, are also acidic with few earthworms. In contrast, soil which develops under some of our broadleaved species, such as tawa, as well

as under deciduous forests and grasslands and where there is a higher calcium content (which makes the pH either neutral or slightly alkaline), tends to be 'mull' humus. Decomposition is rapid because soil biological activity is much higher; the soil is crumbly and less acidic. Earthworms in particular are abundant and they distribute the humus more deeply, mixing together mineral and organic constituents. The distinct layers of a mor soil are not found. In between these two extremes is an intermediate 'moder' humus.

Under pasture, where the nutrients are more rapidly recycled, there are similar niches but these are often occupied by a different, narrower group of organisms. Larvae of the native grass grub (*Costelytra zealandica*) have successfully colonised pasture, feeding on live roots, but in the main, instead of large native insects such as weta one generally finds introduced species such as bluegreen lucerne aphids (*Acyrthosiphon kondoi*); these, as well as the native porina caterpillars (*Wiseana* species) feed on live plant leaves and cause economic damage; nematodes also love the mat of fine roots found in pasture. Introduced earthworms are particularly important aerators and mixers of the soil in pasture and, along with maggots, dung worms are the main consumers of organic material; predators may include mites and various beetles, such as rove beetles (Staphylinidae).

SOIL ORDERS

Given our varied topography, a mixture of old and new, volcanic and sedimentary geology and a multiplicity of forest types, it is not surprising that we have a wide variety of different soils. In general, the oldest and most well-developed soils are found in our oldest part, the North Auckland Peninsula (Northland and Auckland). Many of the soils in Northland and Auckland have been leached of nutrients by the warm, pluvial climate and the kauri forests once widespread there; hence one finds here Granular Soils, Oxidic Soils and Ultic Soils, which reflect long periods of weathering. Allophanic Soils and Pumice Soils are common on the tephra-coated, more central regions of the North Island, while to the east, Brown Soils occur in wetter and Pallic Soils in drier areas. Well-developed, older soils are also common in the western Waikato, Coromandel and Gisborne districts, while youthful soils are prevalent in coastal and alluvial areas as well as around the most recent areas of volcanic activity.

The New Zealand Soil Classification system, developed in the 1980s, classifies New Zealand's soils into 15 different soil orders; each can be subdivided further into soil groups, subgroups and soilforms. Soils are grouped into classes based on similarity of soil properties, not on presumed genesis; the system is designed so that it should be possible to differentiate soils in the field.

The following description of the Soil Orders of northern New Zealand is based on Hewitt and the descriptions given on the Landcare Research website.

ORGANIC SOILS

Organic Soils are dominated by organic matter to some depth, being composed either of

peat or of thick, partly or well-decomposed litter, unlike mineral soils which have only a small organic layer on the surface. Most are found in former and current peat wetlands, in areas such as the Hamilton Basin (notably around the Moanatuatua Scenic Reserve), the Hauraki Plains (in the vicinity of the Kopuatai and Torehape Peat Domes), the Kaituna and Rangitaiki plains in the coastal Bay of Plenty and near Kaitaia.

Organic Soils can be very productive for vegetables and horticulture; they absorb water well but shrink markedly upon drying; following drainage, the classification may change.

GLEY SOILS

Gley Soils occur where the soil is temporarily or permanently waterlogged and are found in low-lying areas with high groundwater tables or around seepages; surface-water gleying

above **Peat being mined from the Torehape Peat Dome, Hauraki District. Note the dark colour, due to it being rich in carbon.**

happens in high-rainfall areas where drainage is impeded by an impermeable horizon such as an ironstone pan. Waterlogging reduces the amount of oxygen in the soil, leading to low levels of soil organisms and, under such anaerobic conditions, the ferric (Fe^{3+}) ions in iron oxides are reduced to ferrous (Fe^{2+}) ions so that the colour of the B horizon becomes blue-grey (the A horizon is usually dark and rich in organic material). A foul smell may be present as organisms turn to alternative sources of energy, generating hydrogen sulfide. Local areas of re-oxidation, created by summer cracking, root penetration or animal burrowing, can cause reddish mottling of such soils. In the natural state such soils supported flax, red tussock and kahikatea forest, but most have been drained to create aerobic

top Estuarine Gley Soils surround the Wairoa River as it enters the Northern Kaipara Harbour, Kaipara District. Podzol Soils are also present further away from the river's edge, and the sand dunes of the west coast are visible in the background.

bottom Drainage canals in poorly drained Gley Soils in a depression in the Hamilton Basin, near Yarndley's Bush, Waipa District. The Horotiu and Te Kowhai soils both formed from rhyolitic tephras deposited on the old floodplain of the Hamilton Basin, but the Te Kowhai soils are gleyed as they formed in poorly drained depressions while the Horotiu soils have much better drainage as they occur on the old levees. Note the remnant kahikatea at the top left of this photo. The small hills in the distance are coated with Ohaupo soils (underlain by Hamilton Ash).

conditions and developed for high-value agriculture such as dairying.

Gley Soils are common in the lower parts of our alluvial plains, including parts of the Hauraki and Rangitikei plains, near Kaitaia and, in the Gisborne District, on the alluvial plains next to major rivers. The volcanic soils of the Waikato basins are also gleyed in the most low-lying parts. Gley Soils on the estuarine margins of our northern half, such as around the Kaipara Harbour, were originally reclaimed from the sea by mangroves; the water table remains high and the Gley Soils here are salty.

ANTHROPIC SOILS

These are soils that have been made or dramatically disturbed by people. Usually they are found in urban areas or areas disturbed by mining, with the original soil either truncated by earth-moving equipment, deeply mixed or overlain by the addition of fill.

MINIMALLY DEVELOPED SOILS

These fresh soils have been little altered by time and in general overlie recent rocks or sediment. Usually younger soils have a lower clay content (as clay takes time to accumulate, unless the parent material contains a lot of clay), are less structured and are less leached of nutrients.

RAW SOILS

These most meagre of all soils either lack distinct topsoil development or are fluid at shallow depths; they have no B horizon, and either no topsoil or one less than 5 cm thick. The vegetation cover is usually sparse, except perhaps for herbs, mosses or lichens. They can be found on the high, cold summits of the Raukumara Range, on the beds of East Cape's braided rivers and along our sandy beaches and tidal estuaries: i.e. anywhere where soil development is prevented by erosion, rockiness or ongoing deposition of more material. Rangitoto Island, being young, is also considered to have Raw Soils. Near Rotorua, one encounters Hydrothermal Raw Soils, where geothermal heat reduces the biological activity (in such soils the mean annual soil temperature at a depth of 30 cm is at least 2.5°C more than the mean annual air temperature).

RECENT SOILS

Recent Soils are generally less than 1000–2000 years old and have only early signs of soil-forming processes, although they have either developed a distinct topsoil or ripened sufficiently that fluid layers are not close to the surface. Some are older but have been truncated or are resistant to alteration. They have at best a poorly developed B horizon, but often have good physical properties for plant growth, a high water capacity and a porous structure which allows deep rooting. They are found in young landscapes such as alluvial floodplains, unstable steep slopes and slopes mantled by young volcanic ash.

Orthic Recent Soils

These are found mostly on the steep hills of the Gisborne District and in scattered locations elsewhere where the high rate of erosion means that well-developed soils cannot form.

Sandy Recent Soils

Particularly common on our exposed western coast, Sandy Recent Soils, since they drain freely, are drought-prone, retain nutrients poorly and, being made of loose sand, are easily eroded by wind if left bare. Many have been planted in exotic forestry, although away from the more exposed sites (e.g. on the leeward side of the Aupouri Peninsula) pastoral farming and horticulture are practised. The Sandy Recent Soils (and Sandy Brown Soils) of the coastal Western Bay of Plenty District are becoming covered in Tauranga's urban sprawl.

Fluvial Recent Soils

Common on floodplains, Fluvial Recent Soils are often very important agriculturally; their composition (e.g. stony or sandy) depends on the parent material. They are usually free-draining and friable. Their location on floodplains makes them prone to flooding and waterlogging; yet, ironically, the more free-draining sandy and stony soils may experience significant moisture loss.

The soils of the Gisborne Plains are some of the most productive alluvial soils in the country, heightened by the relatively warm and pluvial climate compared with the rest of New Zealand's east coast. The soil here is rich in smectite clays eroded from the hills in the catchments of the Gisborne District's rivers. By definition, smectite clays swell when wet and shrink when dry, hence poaching (damage due to trampling) in winter and cracking in summer can occur. The parent rocks also contain lime-bearing sediment, making the soils somewhat alkaline. In the most recent areas, little organic topsoil has yet formed and there are areas of Gley Soils

left **The economically important Gisborne Plains, Gisborne District. The Waipaoa River runs through the middle of the plains, with barer hills in the background.**

in low-lying parts, due to high water tables. However, the slightly older soils, above the flood level, have good aeration, drain freely and are well supplied with nutrients.

Both these and smaller plains further north towards East Cape have expanded since the 1930s, due to deforestation and erosion in their catchments, although the recent, extensive exotic plantations — mainly of *Pinus radiata* (particularly in the headwaters) — should reduce this in the future. Erosion has been a particular problem in the Gisborne District; the Tertiary mudstones and argillites there contain a lot of smectite clays which, when wet, swell and force the rock particles apart; repetitive shrinking and swelling is accentuated by the most unreliable rainfall in the northern North Island and the terrain itself is often rugged with steep slopes.

Other areas of Fluvial Recent Soils include the Rangitaiki Plains; sediments here are predominantly derived from the pumice-lands of the Taupo Volcanic Zone (TVZ), although near the Whakatane River in the east there is a greater amount of greywacke alluvium from northern Te Urewera, giving that area a finer texture and better moisture retention in drought.

Tephric Recent Soils

To the east of Lake Rotorua and extending down to the Rangitaiki Plains are soils which derive from basaltic tephra thrown up by the Tarawera eruption of 1886. They are gravelly, have minimal clay and are prone to drying out. The Tarawera eruption also ejected previously erupted soil-forming material, termed Rotomahana Mud, which is very suitable for dairying.

Rocky Recent Soils

These are found particularly on the high summits of the axial ranges in the east.

INTERMEDIATE SOIL DEVELOPMENT

Allophanic Soils, Pumice Soils and Melanic Soils, while still containing a high proportion of unaltered minerals, have been altered to some degree from their parent rock or sediment and have well-developed soil horizons, if not on shallow rock.

ALLOPHANIC SOILS

Most of our Allophanic Soils are derived from ash and scoria tephra, rich in volcanic glass and feldspar, which was deposited between 3500 and 50,000 years ago by eruptions in the TVZ. Some Allophanic Soils derive from greywacke and basalt scoria or pumice; there are Allophanic Soils around Kumeu and dotted around the North Auckland Peninsula, for instance on the Auckland volcano Brown's Island/Motukorea. They occur in areas where the annual rainfall is greater than 1000 mm per year with at most only short rainfall deficits.

These soils are named for the dominance of allophane and other short-range-order minerals (see above) such as imogolite and ferrihydrite. They are 'greasy' soils, characteristically weak and sensitive, losing strength when disturbed, and have a high or very high natural affinity for phosphorus. Being older, they have a significant clay content (10–25%), although this is still sufficiently low that it is easy to change the balance of nutrients using fertiliser; they are generally loamy in texture.

Allophanic Soils are friable, of low density and deep (therefore lacking barriers to root penetration), resistant to trampling, freely draining, well structured and without significant trace-element deficiencies. They have a high density of soil organisms. Hence, although they are moderately to strongly leached with low levels of exchangeable calcium, potassium, magnesium and sodium, they are generally soils of high value. Because

right **Kiwifruit orchards on tephra-derived soils near Te Puke. Note the incised gully bordering these orchards into which cool air can drain, reducing the incidence of frosts, and the shelter belts to protect against wind. Western Bay of Plenty District.**

opposite **A thin Pumice Soil covers ignimbrite. Western side of Lake Taupo, Taupo District.**

of their limited fertility, for dairy farming they require additional potassium, magnesium and phosphorus.

Bay of Plenty Allophanic Soils

The loamy volcanic soils of the lowland Bay of Plenty (inland from the Recent Soils of the coast and away from the Rangitaiki Plains) originated mostly from Rotorua's Okataina Volcanic Centre between 4000 and 40,000 years ago. They are less leached than those on the higher ground around them (e.g. the Mamaku Plateau), due to the drier climate. These soils form the basis of Te Puke's kiwifruit industry and horticulture around Tauranga Harbour. Those in the eastern Bay of Plenty are less versatile, as the ash is younger and less weathered and the climate drier.

Waikato Allophanic Soils

Allophanic Soils also dominate the various lowlands of the central Waikato, in an arc from Taumarunui through Te Kuiti, Hamilton and around to Matamata, all roughly equidistant from the eruptive centres in the TVZ, as well as the Manukau Lowlands. As one heads further east, rainfall and hence leaching decreases. Rivers have sculpted this area into an undulating landscape, leaving small tephra-covered hills surrounded by depressions from old watercourses. As a result, Allophanic Soils on higher ground are interspersed with Gley Soils which occur in the waterlogged depressions, due to poor natural drainage. Most of the latter have now been drained for agricultural purposes, and this region produces 20% of our agricultural exports. There are also Organic Soils in areas previously dominated by peat bogs.

PUMICE SOILS

Formed from rhyolitic tephra that erupted between 700 and 3500 years ago in the Kaharoa and Taupo eruptions, these more youthful soils have abundant coarse particles dominated by pumice or sandy glass tephra and are crumbly

and erode easily. Some Pumice Soils were deposited as alluvium after the eruptions when pumice dams, which had temporarily raised lake and river levels, were breached.

Pumice Soils dominate the area in and around the TVZ and even spill over Te Urewera to the Gisborne District, although the pumice did not settle in soil-forming quantities on the higher elevations such as around Lake Waikaremoana and in Pureora Forest Park. They consist of an A horizon that varies depending on the vegetation history and a B horizon that becomes reddish brown as leaching increases. The clay that does occur is largely allophanic.

Rhyolitic eruptions are naturally deficient in some rarer but nutritionally important elements, particularly cobalt, selenium and copper. This caused 'bush sickness', a mystery illness of livestock for some years, and led to the establishment of exotic forestry rather than agriculture in the Kaingaroa Plateau. The cause, deficiency of the above elements, was uncovered in the 1930s and the soils respond well to fertiliser, due to their low clay content and weak weathering.

Flow tephra, derived from avalanches of erupted material which includes large objects such as charred logs and incandescent mud swept down with the eruption, may contain sharp shards that are a barrier to root penetration.

MELANIC SOILS

Melanic Soils, which include some of our most naturally fertile soils, are scattered around Northland, for instance in the hills southeast of Dargaville. They contain high levels of calcium or magnesium from lime-rich or mafic or ultramafic (basic) volcanic rocks such as basalt and peridotite. They include abundant soil organisms and have a black or dark grey topsoil with a subsoil of either lime or one that is well developed and neutral or only slightly acidic, usually with abundant smectite clays.

left **A Brown Soil at the eastern end of the Bay of Plenty, Opotiki District.**

Soil derived from lighter-coloured rocks or sediments

Pallic Soils and Brown Soils are derived from silica-rich parent material, particularly quartz, feldspar and mica (e.g. greywacke). They divide into different soil orders based on whether they develop in a semi-arid, sub-humid or humid climate, although only the latter two climates are found in the upper North Island.

PALLIC SOILS

Developing in a less wet (sub-humid) climate with summer droughts, Pallic Soils are predominantly found around the city of Gisborne and the higher parts of the Waipaoa River valley, as well as in scattered locations further up the east coast as far as Ruatoria. They are also common all down the east coast of New Zealand. Pallic Soils have a pale subsoil because of a lack of iron oxides and are susceptible to erosion, but have a medium to high nutrient content.

BROWN SOILS

Nationally these are the most common soils in New Zealand; they have a dark brown topsoil with a brown or yellow-brown subsoil. The brown colour is due to iron oxides, which with aluminium oxides are evenly dispersed through the soil. They usually form from weakly weathered parent rocks, both igneous rocks and greywacke, and occur in areas with more than 1000 mm/year of rainfall where neither summer drought nor winter waterlogging is common. They are rarely dry (unless they are sandy or stony), contain lots of soil organisms (especially earthworms) and are easily penetrated by the roots of native plants; the clay minerals are predominantly mica, illite and vermiculite. They are common on sloping and young land surfaces over the silica-rich sedimentary rocks of eastern Northland, the ‘Pohutukawa Coast’ in southeast Auckland, around the edges of the Hunua and Waitakere ranges and on Waiheke Island; they dominate the Coromandel Peninsula (where they are derived from the older volcanic rocks of that area) and are also

present on the west Waikato coast and in the Opotiki and Gisborne districts — or at least in those parts of the latter where they haven't been eroded away.

There are some Brown Soils (Allophanic Brown Soils) in the Gisborne District that contain substantial allophanic minerals, while those found in the centre of the Aupouri Peninsula and on Matakana Island are dominated to depth by sand or loamy sand. In small areas of Northland, the Bombay Hills and the western Waikato there are also some Oxidic Brown Soils, which are more strongly weathered, although, compared with Oxidic Soils, they still contain significant weatherable minerals and higher levels of magnesium. Some Brown Soils found in central Northland are very acidic.

above **A highly leached Podzol Soil, Ahipara Plateau, Far North District. Note the organic layer on top, overlying a very leached white E horizon through which the roots of the scrubby vegetation are not passing. The B horizon is the ginger-brown layer below (left foreground), the leached iron from above giving it that colour.**

PODZOL SOILS

Podzolisation, the process leading to the formation of a hard, impermeable pan below the surface, occurs particularly in soils derived from silica-rich rocks such as greywacke and rhyolite which have endured a superhumid, pluvial climate (usually over 1300 mm/year) and been covered by kauri, podocarp or beech forest producing mor humus.

Rainwater percolates through the mor humus, dissolving the organic acids which then react with clay minerals to form soluble compounds. Organic and non-organic

nutrients (aluminium and also often iron) are then leached from the topsoil and deposited further down the soil profile, rendering the surface layer acidic and nutrient-poor. As a consequence of this process of eluviation, there is usually a white layer (E horizon) devoid of everything bar quartz. When these nutrients precipitate out, deeper in the soil's B horizon, they turn that horizon a bright ginger-brown colour and can form a hard, impervious iron or humus pan (for instance, in the Densipan Podzols of Northland and the Pan Podzols of Te Urewera). Such pans also prevent the drainage of water. The soils themselves tend to be silty or sandy rather than clayey.

The end result, found only in older soils where there has been sufficient time for this process to take place, is a silty- or sandy-textured, acidic, poorly drained and infertile soil, resistant to root penetration; only with enormous effort and expense can they be made into any sort of useful agricultural or forestry land.

Before the arrival of humans, kauri forest was self-sustaining in such soils, with the available nutrients clustered right at the soil surface. However, after initial forest clearance, in many cases conducted centuries ago by early Maori, the infertile nature of the soils prevented the re-establishment of forest. Those soils that developed on sand, such as on the Aupouri Peninsula and in the sandy hills west of Dargaville, have produced classic podzols, with a pure white E horizon of nothing but silica (quartz). Podzol soils can also be found on the Ahipara Plateau, which was exploited in the 19th century for kauri gum.

In the central North Island, the soils formed from the rhyolitic Taupo pumice are much more inclined to podzolisation than those derived from more basic Tongariro tephra further south, although in the absence of kauri the extremes of podzolisation are much less evident. Podzols may be found on the rainy highlands of the Mamaku Plateau, Pureora Forest Park and Te Urewera; on the flat-topped Mamaku Plateau west of Rotorua, the younger rhyolitic pumice has eroded away to leave older volcanic loams exposed.

The mull humus of hardwood forests such as tawa can reverse podzolisation if they replace podocarps.

STRONGLY DEVELOPED SOILS

These soils occur on old land surfaces that have had sufficient time for the soil to mostly transform into clay. They are common in Auckland and Northland, where the land has generally escaped being severely eroded or covered in volcanic ash.

ULTIC SOILS

Derived from similar quartz-rich rocks giving rise to Brown Soils, but having been stable for a longer time and more strongly weathered, Ultic Soils are common around Auckland, particularly Rodney and the Hunua and Hapuakohe ranges, and are patchily distributed around Northland. They are yellow or yellow-brown and more strongly leached, acidic and nutrient-poor than Brown Soils, and are only slowly permeable and usually poorly drained with a well-structured, clay-rich subsoil (predominantly kaolin, halloysite, vermiculite and smectite). There is also often an E horizon, depleted in clay, beneath the topsoil and sometimes a high-density uncemented pan (Densipan Ultic Soils) at shallow depths. Hard in summer and wet in winter, they are prone to erosion and treading damage (poaching). Large amounts of lime can be used to overcome their acidity and compost to balance their high clay content, but many have been left to revert to

above **An Ultic Soil at Flat Bush, Auckland. Note the brown topsoil and the clay-rich subsoil as well as the accumulation of surface water at the bottom, due to relative impermeability.**

shrubland or used for semi-intensive sheep farming or forestry.

The most strongly leached are very difficult and degraded soils; they usually occur in Northland on gently sloping old landscapes that were once covered in kauri. Their impermeability makes them not dissimilar to Gley Soils and some were once incorrectly classified as podzols.

GRANULAR SOILS

These typically highly productive, clayey soils are only found (in New Zealand) in the northern North Island and are termed granular because they may be easily parted into small, hard fragments. They are formed from prolonged weathering, predominantly of older tephras (mostly over 50,000 years old) but also of basaltic and andesitic rocks; they are sticky and heavy to work when wet, drainage is slow and they have low nutrient reserves. Granular Soils have a well-developed polyhedral structure and are dominated by kaolin-group minerals.

Granular Soils derived from older TVZ airfall tephra (including the widespread Hamilton Ash, deposited around 200,000 years ago) cover areas of rolling, low hill country from around Pirongia and Morrinsville north to Pukekohe as well as on the western border of the Kaimai Range, above the more recent, low-lying Allophanic Soils, but have been removed by erosion from the steeper slopes of the Hapuakohe, Hunua and Hakarimata ranges.

The Patumahoe soils around Bombay and Pukekohe are significantly less leached than those further south and are very good for market gardening, despite their stickiness when wet and low natural fertility. However, some of the higher parts of this region are bereft of this covering of Hamilton Ash and the original basalt is soil-forming on the heights.

above **Granular Soils comprised of Hamilton Ash are used for market gardens around Pukekohe, Auckland.**

Other Granular Soils are derived from the andesites, flood basalts and sheet lava of the older Tertiary and Upper Cretaceous volcanic plateaux of Northland, Great Barrier Island and the Waitakere Ranges. In the high-rainfall areas of the upland volcanic plateaux are the acidic, low-fertility Oxidic Granular Soils; in the highest parts drainage is poor and the soils are waterlogged in winter; the wetting is caused by water perching on a clay-enriched, only slowly permeable layer, hence the name Perch-Gley Granular Soils. The Granular Soils derived from the ultramafic rocks at North Cape have a distinctive flora.

OXIDIC SOILS

Oxidic Soils are derived from andesites, dolerites and basalts of Upper Cretaceous to Pleistocene age. They are friable volcanic clay soils (50–90% clay content) which are very strongly leached, are acidic and have attained a high concentration of iron and aluminium oxides with accumulation of kaolin (allophane being only a minor component); those with a high concentration of haematite (a form of iron oxide) have a striking red colouration. They are common around Kerikeri and in scattered locations in the Auckland urban area and near Whangarei. They come close to exhibiting features of the laterite soils found in humid, tropical climates. Despite very low nutrient reserves, they can be very productive when well managed with fertiliser and irrigation. Kerikeri's citrus orchards are found on these soils.

A NOTE ON THE CHEMISTRY OF WEATHERING

Some of the chemical reactions involved in weathering include the following.

- A combined carbonation/hydrolysis reaction. For instance, the felsic orthoclase (a feldspar) is dissolved by the following reaction involving both carbonic acid (carbonation) and water (hydrolysis):

  $$\textit{orthoclase}\ 2KAlSi_3O_8 + H_2CO_3 + 9H_2O \rightarrow K_2CO_3 + 4H_4SiO_4 + Al_2Si_2O_5(OH)_4\ \textit{kaolinite}$$

  Note that this reaction consumes carbon dioxide that has been dissolved in water to form carbonic acid H_2CO_3; hence, weathering can reduce atmospheric carbon dioxide and thereby affect the global climate. Carbonation is very important in the dissolution of limestone (calcite, $CaCO_3$): a series of reactions with CO_2 in the soil and carbonic acid results in the dissolution of calcium carbonate. These reactions are reversible and calcium carbonate can later be precipitated out, forming structures such as stalactites and stalagmites.

- Oxidation. Oxygen in water reacts with rock components; for instance, the iron in the more mafic ferromagnesian rocks is precipitated out as iron oxides (e.g. haematite → Fe_2O_3) by dissolved oxygen. Hence olivine (a magnesium iron silicate) is oxidised to yield red iron oxide, magnesium carbonate and silicic acid; it does not produce clay minerals since it does not contain aluminium.

- Reduction. This occurs in waterlogged anaerobic environments, e.g.:

  $$2Fe_2O_3\ \textit{(ferric oxide)} \rightarrow 4FeO\ \textit{(ferrous oxide)} + O_2\ \textit{(oxygen)}$$

- Solution. Water acts as a solvent to remove ions, for instance:

  $$SiO_2\ \textit{(silica)} + 2H_2O\ \textit{(water)} \rightarrow H_4SiO_4\ \textit{(silicic acid)}$$

  Molecules such as potassium bicarbonate (K_2CO_3), magnesium carbonate ($MgCO_3$) and silicic acid (H_4SiO_4) are water-soluble; hence, they are carried away by the water doing the weathering, sometimes precipitating out later in that water's journey to form minerals such as limestone and soil features such as iron pans. Quartz is much less soluble that the non-crystalline form of silica (amorphous silica).

In the end, what's left after the above reactions are kaolinite and other similar aluminium-containing clay minerals and mineraloids, derived from the parent aluminosilicates, and haematite. The other major mineral component of rock, quartz (silicon dioxide), is not readily broken down. Hence the major end products of chemical weathering are clay minerals, quartz and haematite.

CHAPTER THREE:

CLIMATE AND WEATHER

INTRODUCTION

The 'winterless North' is a favourite advertising label attached to our region, particularly the North Auckland Peninsula, and some like to call our climate subtropical rather than temperate. However, although in coastal parts frosts are very rare, it is probably an exaggeration to claim such a climate; in truth, we live in a warm maritime temperate zone with, as is usual for temperate climates, prevailing winds from the west and, due to our maritime nature, a relatively small temperature range from summer to winter. In fact, when using a global description of climate, out of 50 sites throughout the whole country 48 fall into the same 'Cfb' category (i.e. warm, temperate and rainy with a cool summer — the average temperature of the warmest month being under 22°C), with the only exceptions being Chateau Tongariro where it is cooler and Alexandra where it is drier. Nevertheless, our region does have a different climate from that of Invercargill even if on a global scale it is not that different.

It is interesting to consider other areas and cities that share our approximate latitude and the differences that landmass, Antarctica, ocean currents and mountains make to our climate. In the Southern Hemisphere, we are at the same latitude as Victoria in Australia and the Pampas of Argentina, both of which have more extreme heat and cold because of their increased continentality as well as a lower rainfall.

When one goes to similar latitudes in the Northern Hemisphere such as those of the San Francisco Bay Area, Virginia and North Carolina in North America, and Tunisia,

above **Graham Land, Antarctica: a key driver of our climate, keeping us cool and maintaining a large temperature gradient with the tropics in both summer and winter which creates wind as air moves from hot to cold and back again to try to even out this gradient; without the movement of air, there would be no climate.**

Shangdong Province in China, and Seoul in Korea in the Old World, things become more interesting.

On average the Northern Hemisphere is warmer at higher latitudes because the Arctic is much warmer than the Antarctic. In particular, the interior of Antarctica never gets very warm at all, even in summer — while the North Pole averages 0°C in summer, the highest temperature ever recorded at the South Pole is –12.3°C and the average daily maximum even in January is –25.7°C, although this is at an elevation of 2834 m. Furthermore, the continents surrounding the Arctic heat up even further in summer, unlike the Southern Ocean. This means that throughout the year there is a large difference in temperature between the equator and the South Pole, such that in general we have stronger winds (the air moves between the poles and the equator, driven by the temperature gradient; the greater the difference, the faster the air moves and the

greater the wind) and reduced seasonality. In particular, our summers are lacklustre compared with those in the Northern Hemisphere, i.e. we still get cold, windy days in summer whereas the north, with more even summertime temperatures over the whole hemisphere, tends to get warmer, balmier summers. Here one should think of Tunisia — not only does that country have the advantage of being in the Northern Hemisphere, but it is also beside the Mediterranean Sea which, being landlocked, heats up very substantially in summer. To the south that country borders the Sahara Desert, which is of course somewhat drier and heats up more than the water around New Zealand, although it can be quite cold at night due to heat loss by radiation under the clear desert sky; in some North African cities (e.g. Algiers and Cairo), snow has been reported in winter.

San Francisco has a maritime climate, as the major driver of its weather is a cool oceanic current which means that, around the bay area, it never gets all that hot; not far from the coast, however, it can be quite a different story — a temperature rise of 5–10°C can often be experienced in the summer months by travelling only 15 km inland. The cool current, the opposite to our warm current (the East Australian), helps to make its climate more similar to ours despite its location in the generally warmer Northern Hemisphere, as does its relative isolation from the continental bulk of North America on the other side of a range of mountains.

Our Asian and eastern North American equivalents have a much more continental climate and a large bulk of land between them and the Arctic rather than sea, making for colder temperatures in winter when polar air descends to their latitudes, as the air does not have a chance to warm up by crossing relatively warm winter seas. Their summers are much warmer than ours, because of increased continentality as well as the lack of the chill factor of Antarctica compared with the North Pole.

Finally, elevation can make a tremendous difference. Tibet is, in general, considerably colder than us even though it is actually closer to the equator; several kilometres of altitude help cool its climate!

Hence, 'moderate' is a feature of our climate. Although most people in our region would expect the South Island to hold the record for the coldest temperature ever recorded in New Zealand (it does), it in fact holds pretty much all the extreme climatic records — the hottest temperature and the sunniest and the driest year in New Zealand were all recorded in the South Island, as well as the coldest, cloudiest and wettest years. This is because the land area is greater, with less maritime influence in some places than anywhere in the north, and the barriers to atmospheric circulation — i.e. mountains — are higher, causing greater extremes of precipitation and wind. Of course, a moderate climate without extremes is ideal from the point of view of the rural backbone of our country.

We can think of climate on three different scales: a planetary scale, in which northern New Zealand lies within the northern portion of the temperate zone's belt of prevailing westerlies; a synoptic scale, familiar from newspaper and internet charts of fronts, lows and highs; and a much more local mesoscale, in the order of magnitude of one valley to the next or one thunderstorm to the next — there are, for instance, significant differences in climate between frosty Henderson and sunny Waiheke, despite them both being suburbs of the same city, Auckland.

THE BIG PICTURE: THE CIRCULATION OF THE EARTH'S ATMOSPHERE

On a planetary scale, the circulation of air is driven by the transfer of heat between the equator, which receives strong sunlight from directly overhead, and the poles; warm air flows towards the poles and cold comes back the other way.

At and around the equator, intense heating of the air at ground level occurs because the sun is straight overhead (on average, although this varies depending on the time of year). Warm air is lighter than cold air because it is less dense and hence it rises, up to 16 km high. This moving away of air from the ground results in a zone of relative low pressure, the Inter-Tropical Convergence Zone or ITCZ, at ground level (because the air is rising, there is a corresponding zone of high pressure

below **The other end of the temperature gradient and driver of the Earth's climate: warm air rising, cooling and condensing, forming cumulus clouds over Savai'i, Samoa. It will then head polewards, bringing its equatorial warmth to our latitudes.**

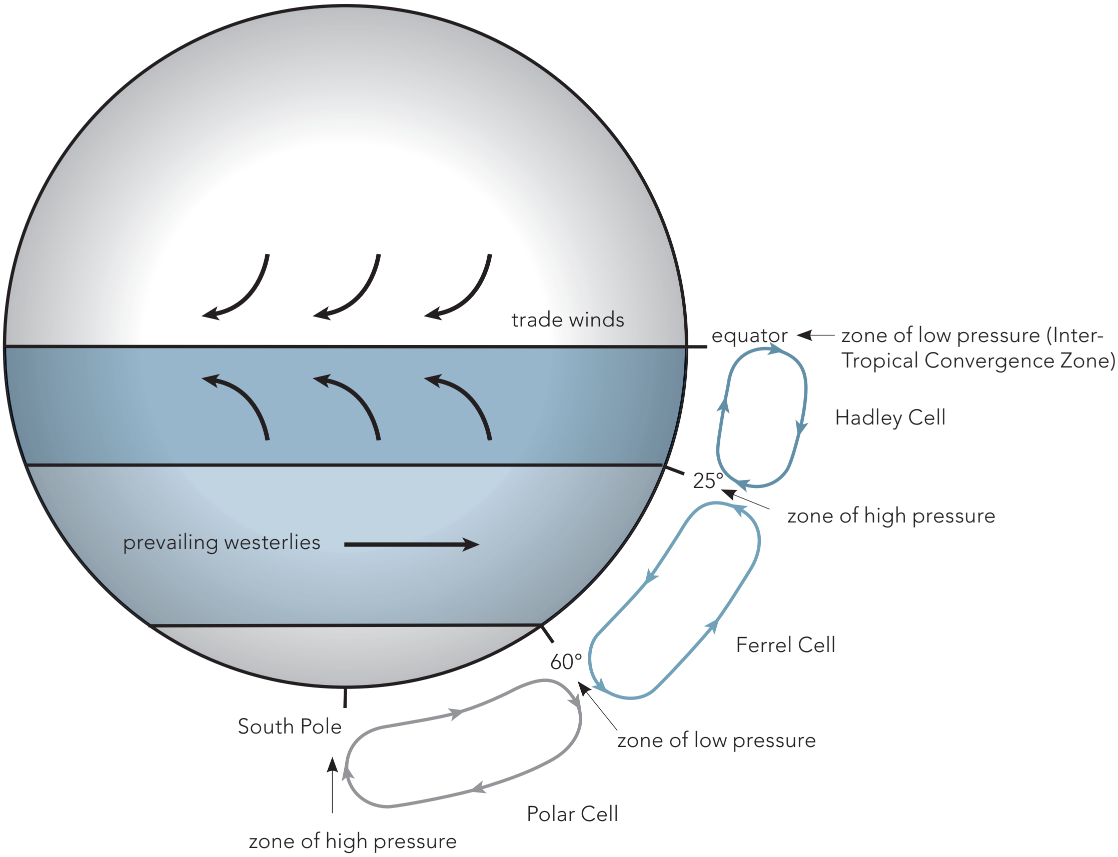


Figure 1
Atmospheric circulation on a planetary scale.

aloft). However, although the air pressure at ground level is low compared with elsewhere at ground level and the air pressure aloft high relative to elsewhere at that altitude, nevertheless the pressure aloft is still lower than that at ground level. Therefore, as the warm air rises it cools, as a result of expansion due to the lower atmospheric pressure higher up. It then travels at altitude to around latitude 20–30° S where it subsides in the so-called subtropical anticyclone belt of high pressure (at ground level) and returns back to the equator at surface level as the trade winds; air always moves from an area of high pressure to an area of low pressure, and the movement of air is what leads to wind. This air movement is known as the Hadley Cell.

The trade winds (indeed, any winds from the south) come from the southeast rather than from due south, because of the rotation of the Earth; this deflection of air coming towards the equator from the South Pole is said to be caused by the 'Coriolis force'. Similarly, winds travelling away from the equator do not

travel directly south but rather arrive from the northwesterly quarter. This deflection becomes less noticeable the more one travels towards the poles, as the circumference of the Earth lessens and, with it, the angular velocity at any particular latitude.

As air cools it is able to hold less water vapour (the amount of water vapour held in the air, as a percentage of the total amount that air can hold at that temperature, is referred to as the relative humidity). When the air cools to the point where it can no longer hold all the water vapour in it (air that is holding as much water vapour as possible is called 'saturated'), water then condenses out of the air, making clouds and rain. Hence, the tropics, with their rising columns of cooling air, are pluvial. Conversely, subsiding air warms and as a result is able to hold more water, leaving none available to form clouds or rain; thus in the subtropical anticyclone belt there is a worldwide zone of deserts, albeit with interruptions where local conditions favour more rain and break this general pattern.

The ITCZ is not fixed; it moves south in our summer and north in our winter, pushing the Hadley Cell south and north with it. In general, its average position is at the latitude of the equator, although in the eastern Pacific it remains north of the equator all year round, due to the influence of Antarctica. North of New Zealand, in the vicinity of Fiji and Samoa, there is also a southeasterly-trending branch of the ITCZ called the South Pacific convergence zone (SPCZ). The position of the belt of high pressure in our region is also affected by seasonal changes in the large continent to our west from where our weather often comes, namely Australia. In summer, the air over the centre of that continent becomes very hot, rising and expanding to form an area of low pressure that pushes the high-pressure zone out over the Great Australian Bight, which is at a latitude similar to our own. This high-pressure zone may in turn extend a ridge of high pressure over the Tasman Sea, causing dry weather in the vicinity of the northern third of the North Island, with intense westerly winds further south, below this anticyclone, due to the large temperature differential between warm central Australia and the cool Southern Ocean; the peak zones of anticyclone activity in our part of the world are in the Great

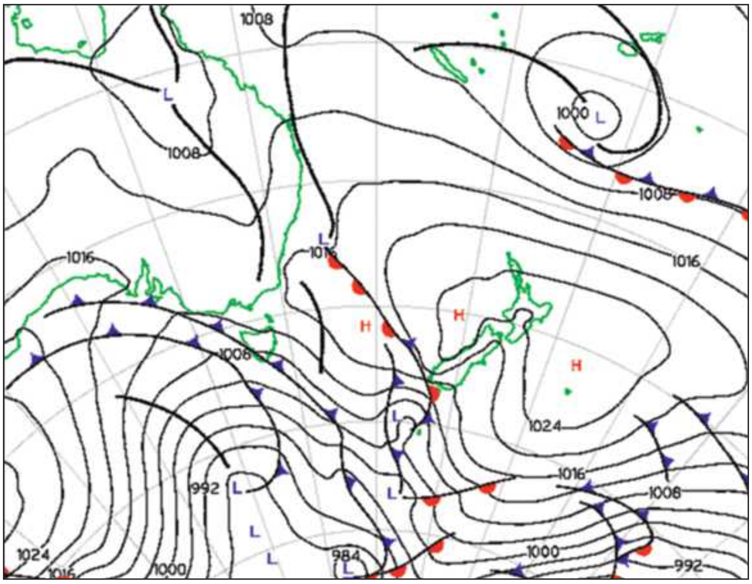


Figure 2 **A high over northern New Zealand in summertime; this was a particularly dry summer, dominated by high pressures in January and February 2013. Image reproduced courtesy of the Meteorological Service of New Zealand Ltd (chart dated 1 a.m. Thursday 31 January 2013).**

Australian Bight and just west of the North Island. Hence, as one goes further north into Auckland and Northland there is increasingly a summer rainfall minimum, while more southerly parts of the country can get strong, miserable westerlies in summer. In turn, this summer water deficit means that despite its warmer temperatures and greater average annual rainfall, grass growth over the whole year in Northland is on average less than that of Southland, since growth is limited in summer by lack of moisture.

Also in summertime, northern New Zealand can experience significant easterlies — which are otherwise rare — coming from the southern edge of the trade winds and moving westwards around the north of the high-pressure belt, heading for the ITCZ which has moved south in our summer. A characteristic of the trade winds is that air and moisture become trapped under a subsidence inversion, whereby the air temperature suddenly increases (and the humidity decreases) above a certain altitude, preventing further upwards vertical motion of the air nearer ground level; as a result, we can get low clouds during these outbreaks.

Conversely, in winter central Australia cools dramatically; the dense, cool air thus produced sinks, pulling the high-pressure zone over central Australia (at this time of year, therefore, the maximum anticyclone peak is over inland southeastern Australia). This leaves us exposed to winds which tend to come more from a southwesterly direction and are able to extend further north, although these winter westerlies which affect the whole country are not as strong as southern New Zealand's summer westerly winds. As a result, while northern New Zealand experiences its worst weather in winter, the most southerly part of the South Island's west coast, the notoriously pluvial Fiordland, often experiences its best weather in winter. Westland also enjoys better weather in winter as southerlies are more prevalent at that time of year; while these inflict cold stormy weather on the southeast-facing Southland, Otago and Canterbury, Westland lies in the lee of such winds, where the air is subsiding having crossed the Southern Alps, and as a result enjoys fine weather at these times. This is similar, in a more marked fashion, to what we can experience in most of the northern North Island, excluding Gisborne, being sheltered by

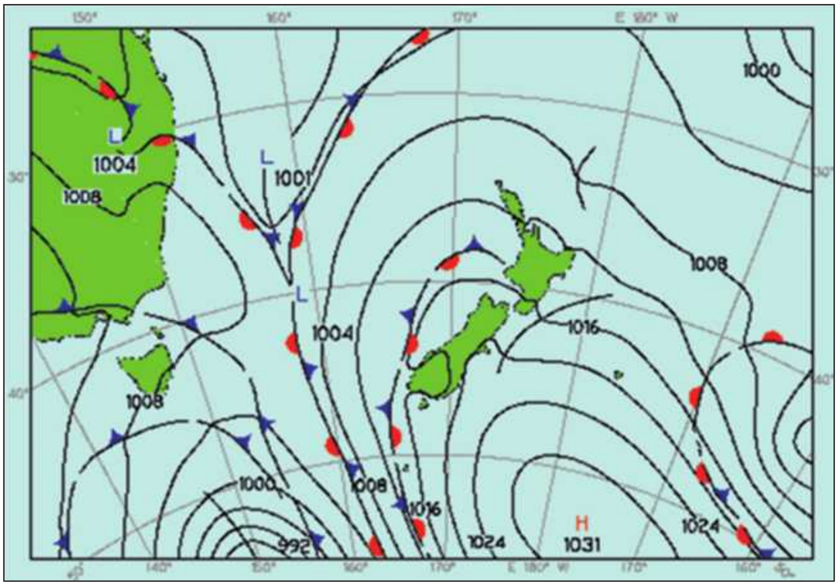


Figure 3 **A high to the southeast sends an easterly flow across northern New Zealand during summer. To our south, Dunedin is receiving northerly winds. Image reproduced courtesy of the Meteorological Service of New Zealand Ltd (chart dated 1 p.m. Tuesday 7 February 2012).**

above **A drought following a dry summer in the north (17 April 2010). Tiritiri Matangi Island, Auckland.**

the North Island's axial ranges in a southerly blow.

A similar zone of high pressure exists at the South Pole. Air descends and moves away from the pole at low levels to around 60° S, where it rises and returns to the pole at high levels, forming another cell which we call the Polar Cell (Fig. 1). Winds again appear to come from an easterly direction (the polar easterlies). The 60° S latitude is an area of low pressure, therefore, in which are spawned the depressions of the Southern Ocean. Winds are much more furious in the Southern Hemisphere than in the Northern. This is partly because Antarctica's ice cap reaches an altitude of about 4000 m in the polar plateau and then slopes down towards the coast; wind picks up speed as it moves down this slope (a katabatic wind). It is partly also because we are one of the few landmasses at our latitude; land is uneven and leads to friction, slowing winds down. The lack of land in the Southern Ocean leads to increased wind strengths. This combination means that cold, polar air masses (and Antarctica is much bigger and colder than the Arctic) are much more able to penetrate to our latitude than they can to similar latitudes in the Northern Hemisphere — and when they do, we certainly know about it. It also means that the Southern Ocean spawns the biggest depressions of them all. This cyclonic activity varies with the season; winter cyclonic activity both is more intense and occurs at a higher frequency at around 40° S as well as polewards of 50° S, while in summer, although the depressions continue spawning in a ring around Antarctica they are not as frequent on our southern boundary.

THE MIDDLE LATITUDES: OUR HOME

Although we are influenced by the large-scale phenomena to our north and south, in truth we belong to the middle latitudes (northern New Zealand, according to the definition of this book, ranges from 34° S to 39° S) — the battleground between the anticyclones of the subtropics and the cyclones of the Southern Ocean, with air moving both ways between them and generating a constant succession of highs and lows. This situation is similar to that in the United States, which at least in part shares a relatively similar climate, but different from that in Northern Europe which, because it is at a much higher latitude, is more directly in the path of depressions; these, for us, are based over the Southern Ocean well to our south.

In more technical terms, one can refer to the 'Ferrel Cell' in these latitudes, with air flowing at low levels away from the subtropics, veering to the east (our westerlies) and returning from the poleward boundary at high levels (Fig. 1), but it is nowhere near as simple and organised as the circulation in the Hadley Cell. Rather, there is a generally westerly flow of air, with areas of high pressure (anticyclones, or 'highs') alternating with areas of low pressure (depressions, or 'lows') that markedly change the direction of the air flow. Warm air from the subtropics is transported polewards between these areas, on the eastern flank of the depressions (which is also the western flank of the highs), rising as it does so over colder air from the poles and hence cooling, causing condensation, clouds and rain to occur. Cold air from the poles is similarly transported towards the equator on the western side of the depressions, subsiding as it does so. Thus, in the Southern Hemisphere air travels in a clockwise direction around lows and in an anticlockwise direction around anticyclonic highs — easy to remember!

We refer to narrow streams of high-velocity winds (around 40–80 m/second) as 'jetstreams'. These bands of air may be thousands of kilometres in length, 2–4 km deep and hundreds of kilometres wide and are predominantly found near the tropopause (the point at which air, now extremely dry, stops cooling with increasing altitude; this sets a ceiling for the troposphere, that part of the atmosphere in which our weather is generated, at between about 6 and 18 km high, being higher at the equator and lower at the poles). The polar jetstream lies at about 10–11 km up, between 40° S and 60° S (the southern boundary of our area being 39° S) and is associated with polar-front depressions; it may meander and sometimes is discontinuous. The subtropical jetstream is at about 12 km high and 25–30° S (slightly north of us), at the poleward border of the Hadley Cell, and is much more consistent than the polar jetstream; it may reach speeds of 200 km/h and is maximal in winter, separating cooler and warmer air masses, but it can move and when it does so it causes significant disturbances in the weather pattern. Both these airstreams flow from west to east. Lows at the surface tend to follow the path of the jetstream, as it sucks up the air into it. Other, less meteorologically significant, jetstreams also exist, including ones flowing in the opposite direction.

WIND

Because we lie in the path of the mid-latitude westerlies, our weather, in general, comes from that direction, perhaps more often from the southwest than straight west. At lower altitudes than the jetstream, the weather fluctuates with the passage of anticyclones and depressions coming in from the Tasman Sea to our west; these are more active in winter and bring more rain during that season, as already mentioned. However, we don't just get westerlies; the highs and lows constantly jostle for position, causing northerlies and southerlies also. We can even get easterlies, for instance when there is a high over the Chatham Islands, more commonly in summer when the highs are usually further south.

There are also many smaller-scale features that create their own winds. Rivers of air can form around terrain features such as the Raukumara Range; when a high approaches that area, with its subsiding air held close to the ground, preventing escape upwards, the winds travelling northwards around the eastern side of the high can get squeezed around East Cape at high velocity, even though highs are normally associated with light winds. This will then cause easterlies across the Bay of Plenty and through the Colville Channel.

In general, wind at low level tends to slow down when it hits land due to friction from the ground, but land can also cause wind. Afternoon sea breezes are common beside the sea; as the land warms during the day it heats the air above it, causing it to rise and, because that leaves behind an area of low pressure, sea air is sucked in off the ocean. As the breeze builds during the day it gradually takes on a relatively uniform direction, due to the Earth's rotation; air rising off the Manukau Harbour at low tide on a hot day can give rise to a strong wind that funnels over Auckland city, squeezed as it is between the Waitakere and Hunua ranges on either side of the isthmus.

In a similar fashion to sea breezes, complex terrain can also cause air movement and, if it leads to vertical motion, clouds. Localised hot-spots may develop over north-facing slopes during the day, causing the air to rise up the slope (an anabatic flow) and pull air from other areas; bare rock works better than fields, and fields better than forest in this regard. Similarly, at night cold air, being denser, flows down to lower ground. This classic mountain–valley circulation can give rise to clouds forming over our hills during the day, and to fog in the valleys at night.

TROPICAL STORMS

Although in summer we often experience more fine weather, due to the proximity of the zone of high pressure to our north, storms can also approach from the north and east and violent weather can be experienced in areas exposed to such winds. The warmer the air, the more water it can hold and therefore the more potential it has to cause a deluge. About once a year, ex-tropical cyclones, moving in a generally southeasterly direction, arrive on our shores, usually in late summer and early autumn. This reflects both the cyclone season in the tropical South Pacific, which usually lasts from November to April, and also the fact that at these times of the year the sea around us is at its warmest, allowing the cyclone to retain more of its energy. In addition, as one moves into autumn there is more chance of encountering an outburst of cold air from the Antarctic, which intensifies these storms.

However, by the time they reach us such cyclones have significantly weakened and they are not as violent, due to the water over which they travel to get to us being cooler than in the tropics; they are thus known as 'ex-tropical cyclones' (although the term 'cyclone' is still commonly but incorrectly used for such storms in the general media). Although packing less of a local punch, they

can spread out over a larger area. Most tend to track down the east coast of Northland to the Coromandel and then veer eastwards to East Cape, avoiding the Waikato Region.

The worst storm to hit New Zealand in the 20th century was a deep ex-tropical cyclone. It crossed the North Island on 2–3 February 1936; every major river in the North Island flooded, with Northland's Mangakahia River rising by 19 m. There were widespread slips, washouts and flooding; windows were blown in by the wind and telephone, power and telegraph lines were cut in many areas. Forty boats sank on Auckland's Waitemata Harbour.

Another example is Cyclone Bola in March 1988, which caused gales, flooding and massive slips in Gisborne District, even though by the time it hit our shores it was of course an 'ex-tropical cyclone'.

SOUTHERLIES

Gisborne District is more exposed to southerlies, which are more common in winter than in other parts of northern New Zealand, which is relatively protected

above **The remnants of a ex-tropical cyclone lash Wainui Beach, Gisborne District, with northeasterly winds, Saturday 22 January 2011.**

from that direction (although not from the southwest) by the bulk of the rest of the country. Southerlies occur as a low passes to our east; the increased southerlies of winter, in general, contribute to the Gisborne District's winter rainfall maximum to a greater degree than does the movement of the Hadley Cell, the cause of the winter rainfall maximum further north. However, a good southerly blow can certainly affect the rest of us, causing snow to fall particularly on the higher ground of the more central parts of the North Island, often followed by a clear but crisp day.

EQUINOCTAL GALES

Equinoctal gales are another feature of our winds. In the spring and autumn, the temperature difference between Australia and Antarctica is maximal, driving the winds in the Southern Ocean faster and causing increased gales at this time.

right **Fog forming in the western Waikato on a still evening, viewed from near the summit of Mt Pirongia, Otorohanga District.**

opposite **Frosty morning, Omaha, Auckland; note, however, the lack of frost on the hillside — the coolest air has settled in the lowest geographical feature.**

RAIN OR SUNSHINE?

Whether we get a warm and sunny day or a cloudy and rainy one, or one with showers on and off, depends on a number of different variables, such as wind, geography, temperature and even time of day. Before we turn to a discussion of fronts and temperatures, we should perhaps first consider the conditions under which clouds and rain occur.

DEW, FROST, FOG AND INVERSION LAYERS

Cloud and fog occur when air becomes too saturated with water vapour to be able to contain all the water within it and condensation occurs. This usually happens at altitude, when initially warm air becomes cooler and therefore less able to hold water, forming clouds, but fog, or ground-level cloud, is well known in the cool, still Waikato nights and causes headaches when it closes our largest airport, in Auckland.

Once night falls, the first form of water to accumulate on the ground (or on one's tent!) is dew. As the ground temperature drops, due to radiation of heat out into space, the air right next to the surface loses its own heat to the ground by conduction and convection, eventually dropping below its dew-point temperature so that condensation occurs. As a result, dew starts to coat the ground. Frost forms when the temperature at the ground falls to freezing.

Fog may be produced as a result of diabatic cooling (cooling without vertical motion) by several different processes.

- Radiation fog occurs by the same process as dew; a couple of hours after dew starts condensing on the ground, the air around it may become cold enough that condensation occurs within the air mass and fog appears. When there is a frost it takes longer to form fog than if there is just dew present. Cloudless nights are also better for both dew and fog


as there is more radiation heat loss from the ground because heat is not trapped within the atmosphere by clouds and thus the temperature drops precipitously, especially over long winter nights. The resulting larger temperature drop of course also makes frost more likely to occur on cloudless nights, especially in winter where the air starts off cooler.

- Advection fog is caused when warm, moist air is transported over a cold surface, lowering its temperature abruptly; this can be seen most obviously (albeit outside our region) in the large fog banks that may be present in the Southern Ocean at the Antarctic convergence when, in a northerly wind, warm air is driven across the abrupt drop in water temperature that the convergence represents. We experience a similar situation when humid northerlies drive warm, moist subtropical air over our region, because this air comes to our cooler climes from warmer ones already saturated with water.
- Steam fog occurs when cold air flows over comparatively warm lakes, rivers and swamps — such as the Waikato River and Whangamarino Fen in winter; moisture evaporates from the warm water into the cold air but immediately condenses again once it hits that air. These areas are also prone to fog since they tend to lie in valleys that are sheltered and accumulate cold air that, being denser and thus heavier than warmer air, tends to flow down into such regions, especially on still nights.

It should also be noted that fog, or cloud at ground level, can be caused by orographic lifting (see below) of warm humid air which encounters higher ground, forcing it to rise and cool; this is known as ‘upslope fog’.

If one is at altitude, one often notes that the fog is confined to the valleys and has a flat upper surface. This is due to an inversion layer forming; the air below, in the fog, has been cooled by being close to the ground

(within, say, 50 m) and, as a result, is cooler than that at altitude. Air cannot rise past such an inversion layer and hence the fog becomes trapped under this layer. When the sun comes out in the morning, the fog 'lifts' as the temperature of the air close to the ground warms up.

In general, wind is the enemy of fog as it causes warm, dry air to be mixed down into the cool humid air by the ground or other cold surface, breaking it up. However, light winds can create a thicker, denser fog by gently mixing the air near the ground, sufficient to cool a deeper layer of air without blowing it away completely; in effect, it lifts the fog that has already formed up from the ground, allowing yet more fog to be created at ground level without blowing the fog away.

CLOUD AND RAIN

Most cloud occurs at altitude rather than lower down as fog. There are several different causes of cloud development and subsequent precipitation, all of which require the vertical ascent of air to cool it to the point where it can no longer hold all the water vapour it carries and thus triggering condensation. These methods include:

- low, prolonged uplift of air in a low-pressure system (cyclonic lifting)
- convection, either free (due to warming of the air close to the ground during the afternoon, causing an unstable atmosphere) or forced (such as by depressions and fronts forcing air to move and creating conditional instability of the atmosphere — see below). Convective instability can also be found at the western side of a cyclone, where relatively cool air is drawn towards the equator over relatively warmer sea

below **Orographic cloud formation: stratocumulus cloud is collecting over the higher hills of the western Waikato, such as Mounts Karioi and Pirongia, while sparing the lowlands and sea. Cirrostratus cloud is also present at altitude. Waikato, Waipa and Otorohanga districts.**

CONDENSATION AND PRECIPITATION DUE TO ADIABATIC COOLING

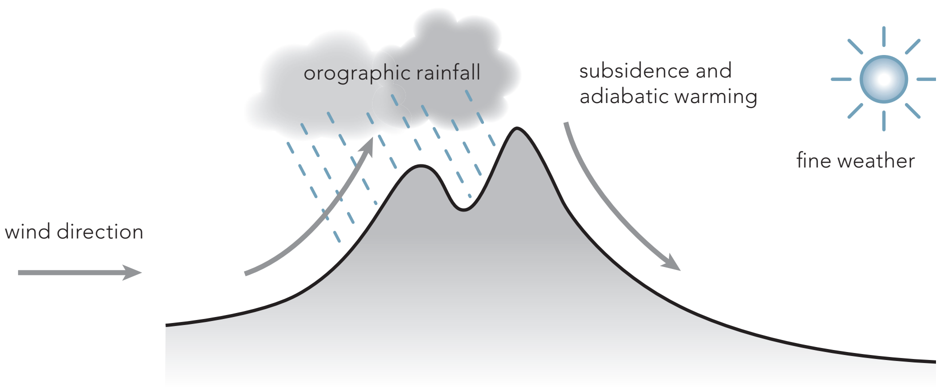


Figure 4
Formation of orographic clouds and rain, a result of the uplift of air over ranges perpendicular to the wind direction. Adiabatic cooling and warming refers to temperature changes caused by such vertical movement of an air mass, which gives rise to a warm foehn wind on the leeward side (see text).

- orographic effects, where mountain ranges force air up as it moves across them. This could also be considered a type of forced convection (Fig. 4)

Meteorologists divide precipitation into 'rain' and 'showers', with rain coming from large flat nimbostratus clouds formed by low, prolonged uplift over a large area and lasting for days, and showers coming from cumulonimbus clouds with strong uplift locally in scattered parcels of air, dispersed among subsiding air coming back down around them to replace the lost air, and usually lasting less than an hour — although heavy showers which remain stationary over one place can cause flooding.

Often our rain is a product of all three methods — a cyclone (depression) moving across the North Island causes cyclonic lift; ranges (such as the Waitakere, Coromandel and Raukumara ranges) get hit even harder because of orographic lifting and, at the fringes of the cyclone, convection currents suck in more air, creating conditional instability (see below).

Exactly how water condenses into cloud is not known, but it is thought that in supersaturated air, moisture must have something to condense onto, such as particles of dust or sea salt. The droplets in clouds are so small that they are pushed up more by the updraught within the cloud than they are pulled down by gravity; hence, they stay aloft. In New Zealand, to get rain the cloud must usually be above the freezing level, so it is actually ice crystals that are formed. These then capture water vapour from the air, sucking enough vapour out of the air that the humidity drops below 100%. This causes the evaporation of other small water droplets into the air as water vapour, which then deposits on the ice crystals, feeding the process. The ice crystals eventually become big enough to be affected by gravity; as they fall, they become even bigger since, on their way down, they encounter more water droplets which then freeze onto them. In the upper North Island, these ice crystals (snow) usually melt into rain before they hit the ground, except at altitude in winter. Drizzle is formed by the

same mechanism as rain except that the drops are smaller, being formed in less dense and thinner cloud whose weaker up-currents are not able to hold up drops as large and heavy as rain before gravity causes them to fall.

Warm rain can occur if water droplets in clouds bump into each other, building up and then falling, but this process is much less efficient. Otherwise, the necessity of forming ice explains why cumulus clouds can lead to showers more readily in winter than in summer; in winter, precipitation may form in clouds as low as 800 m over Auckland but must be much higher in summer.

Thunderstorms

A dramatic weather pattern, thunderstorms are the result of huge updraughts and rain generated within cumulonimbus clouds in very unstable atmospheres, often at a front. Warm air rushes up until it is stopped by meeting even warmer air, often at the tropopause. This gives rise to a characteristic, anvil-shaped cloud. The air cools and condensation occurs, creating even more instability, before falling as rain. If the updraughts are strong enough, the water droplets can form balls of ice large enough not to melt on the way down, giving rise to hail.

It is thought that a separation of charge occurs within the rain droplets, giving rise to static electricity which then discharges to the ground in the form of lightning and associated thunder. Often cumulonimbus cloud produces only short bursts of rain, as the rain coming down gives rise to downdraughts that can dissipate the storm, but if there is a slight wind aloft this can carry the top part of the cloud (and therefore the rain) away from the updraughts produced lower down, allowing the storm to continue (Fig. 5).

Convection: stability and instability of the atmosphere

We have already seen that uplift of air is critical to the formation of clouds and rain; we now need to consider how such uplift happens, particularly in the absence of an

THUNDERSTORM

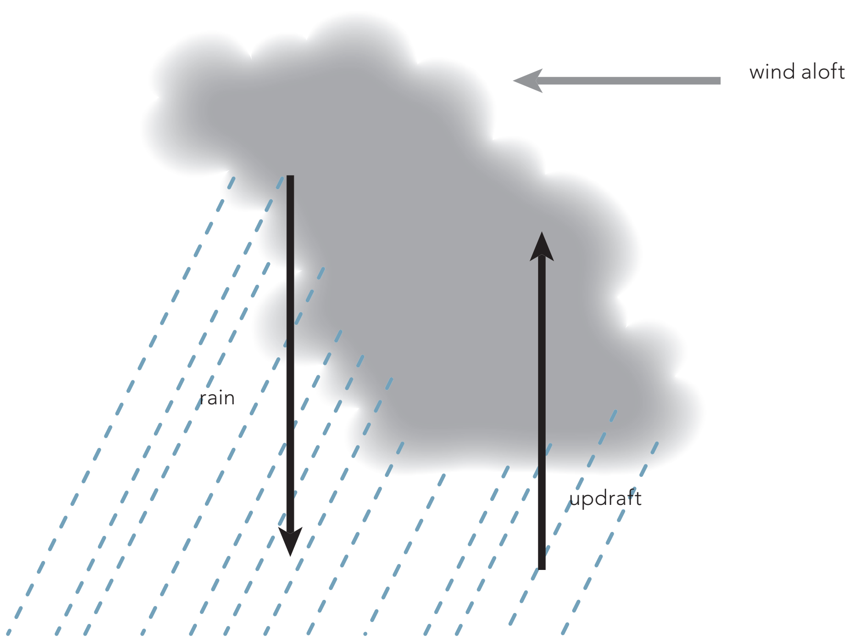


Figure 5
Formation of a thunderstorm (see text for explanation).

above **A front passes over, travelling east parallel to the eastern Bay of Plenty coastline. Thunderstorms are being generated by the cumulonimbus clouds of this front. Opotiki District.**

obvious source of uplift such as wind blowing air across a mountain range. This requires an understanding of convection, or movement of air, within the atmosphere.

Air will move upwards when there is an 'unstable atmosphere'. Consider the atmosphere as consisting of little parcels of air. Warm parcels of air low down in the atmosphere are often generated by a heated land surface during the day; they rise because warm air is less dense than cool air and hence these parcels are more buoyant than the air they encounter around them at higher altitudes — this is called 'free convection'. These pockets of air then expand (due to lower air pressures at altitude) and, because they are expanding, cool as they do so, at a rate of about 1°C per 100 m (the dry adiabatic lapse rate). This cooling is called 'adiabatic cooling', as occurs due to a pressure change rather than an exchange of heat with the surrounding environment. Air that is saturated with water releases heat as the water condenses, keeping it warmer and meaning that it does not cool as much (between 0.4°C and 0.7°C per 100 m). Air parcels keep rising as long as they remain more buoyant than the surrounding air, which, as it remains warmer, is more likely to happen with saturated air that is experiencing condensation. In general, as one ascends higher into the atmosphere the temperature of the air already present becomes colder (the environmental lapse rate), before warming again at very high altitudes; this latter phenomenon (temperature inversion) will then stop vertical air movement above a

above **Forced convection forming cloud: the sand hills of the Awhitu Peninsula, Auckland, force up humid air travelling in a westerly wind, causing condensation and cloud formation.**

certain altitude, since cold air cannot rise into more buoyant warm air.

In a stable atmosphere, a parcel of air that moves up will encounter air that is not particularly cooler than it; if it moves down, it will encounter air that is not particularly warmer than it (the environmental temperature profile). Because the parcel of air must cool and warm due to pressure changes (the adiabatic lapse rate) as it moves up and down, it cools more than the surrounding air when it goes up and vice versa when it goes down, making it less buoyant as it moves up and more buoyant as it moves down; this tends to cause it to return to its original level. When large standing waves of air are generated by air blowing across a mountain range in stable atmospheric conditions, lenticular clouds may form (if the humidity is sufficient) as the air rises towards the crest of a wave (such that the air parcel is moved up and cooled), and then dissipate as the air descends into a wave trough. Such clouds can remain in the same place even though the wind blowing through may be travelling at 100 km/hour or more.

Conditional instability may occur when a parcel of air is pushed upwards (forced convection) from a stable atmosphere into an unstable one higher up; this can change small cumulus clouds into towering cumulonimbus rain clouds. Because air is able to hold less water when it is colder, condensation may occur when air is forced up; this leads to a decrease in that air parcel's adiabatic lapse

rate, making it more buoyant and increasing the chance of an unstable atmosphere. Such forced convection can be due to wind blowing air over hilly terrain and forcing the air up (i.e. the orographic effect), weather systems such as troughs moving across a region, or the afternoon temperature difference between warm land and cool sea, particularly in summer, causing air to move onto the land (as sea breezes). To take frontal systems as an example, in a cold front the incoming denser and heavier cold air slides under the warmer air already present, lifting it. Similarly, in a warm front the initial wave of warmer air is forced above the cold air already present, lifting it.

AIR MASSES AND THEIR MOVEMENTS

It will be obvious from the previous section that whether we get conditions favourable to rain or to sun will depend on the composition of the atmosphere, which in turn depends on where the air comes from and how it interacts with other air masses.

AIR-MASS SOURCE REGIONS

Air masses are large, relatively uniform bodies of air, millions of square kilometres in area, that form over sections of the Earth's surface that have relatively uniform characteristics (such as the Pacific Ocean) and persist for at least 4–5 days. Given our location, it is hardly surprising that the air masses that affect us are maritime in origin! When one type of air mass comes to dominate, our weather reflects its characteristics.

One feature we can use to distinguish between the different air masses is their dew point, the temperature below which water vapour in a volume of air at a constant pressure will condense into liquid water; this is called dew when it condenses onto a solid surface. If the air pressure rises while the relative humidity remains constant, the dew point will also rise. As it is able to hold more water, warmer air will tend to have a higher dew point, although of course — being warmer — it may or may not be more likely to actually cause dew; the formation of dew depends on the relative humidity, i.e. how saturated the air is with water. Air with a higher dew point, unless particularly dry, will feel more muggy — above about 21°C, many will find such humid air oppressive.

The air masses that affect us include, from south to north:

- Modified polar maritime (MPm) — from the Southern Ocean at the edge of Antarctica (between latitudes 55° S and 68° S). This air is cold, moist and unstable, bringing snow to our higher altitudes and generally cold temperatures in a strong southerly. It has a dew point of 2–7°C.

- Southern maritime (Sm) — from the Southern Ocean, from between 35° S and 55° S with a dew point of 7–13°C. It is unstable at low altitudes but stable aloft, and tends to give days which are cool, moist, cloudy and drizzly with heavy rain where it is lifted orographically.

- Tropical maritime Tasman (tTm) — from the North Tasman Sea, giving us warm, moist, cloudy and drizzly weather with a dew point of 13–18°C. Once again, there may be heavier rain over higher terrain.

- Tropical maritime Pacific (pTm) — coming to us from a northeasterly direction, we occasionally get a mass of pTm air over us, with a dew point of 18–21°C: muggy, humid and cloudy!

SYNOPTIC-SCALE CIRCULATION

DEPRESSIONS

Depressions (areas of low pressure, associated with rain) commonly originate in the Tasman Sea because:

- the jetstream slows down over the Tasman Sea, lowering the air pressure at sea level
- air moving eastwards towards New Zealand passes over the Great Dividing Range in Australia and is disturbed by that terrain feature, causing a process called lee cyclogenesis (i.e. causes the formation of depressions)
- cool air from Australia takes on more moisture as it crosses the Tasman Sea, while at the same time the warm East Australian Current (EAC) also heats it, allowing it to carry more moisture; both these factors contribute to an unstable atmosphere.

As shown on an isobaric chart, air generally moves along isobars which, since air travels in curved lines, are also curved. Winds move clockwise around depressions (in the Southern Hemisphere), so that ahead of a depression there are usually warm winds from the north which may bring heavy rain to our region, and to the rear are westerly showers or southerlies. These take about 1–3 days to cross over our country from west to east.

Depressions are associated with cloud and rain because they represent an area where air is rising and hence cooling, meaning that it can no longer hold as much water as before (cyclonic lifting).

ANTICYCLONES

Anticyclones, or areas of high pressure and descending air, often bring clear skies (except when the wind is onshore, when they usually mean cloudy weather in New Zealand). They can take only 1–2 days to cross the country, although sometimes can remain stationary for longer (e.g. 5–7 days). Winds move in an anticlockwise direction around an anticyclone, so if they are to our east they will produce northerlies or northwesterlies and if they are to the south there will be prolonged southerlies or southwesterlies. Subtropical anticyclones are more common in late summer and autumn and are found around 30–40° S (i.e. our latitudes).

The good weather commonly associated with an anticyclone is a result of the subsiding air gradually warming as it descends, due to higher pressures closer to the Earth's surface; air can hold greater and greater amounts of water as it descends and warms, so cloud and rain do not form.

Blocking anticyclones, which are not uncommon and may be governed by a wave structure in the upper-level westerlies that circle the globe in our latitudes, can give us fine weather for days if they are right over the top of us. These are basically very strong anticyclones, present right throughout the depth of the troposphere; air in the upper atmosphere moving west to east is held up by this obstacle and has to flow around it, causing slowing of the flow upstream until eventually it pushes the anticyclone away. Of course, what type of weather results from a blocking high depends on its location; one which is only slowly moving across New

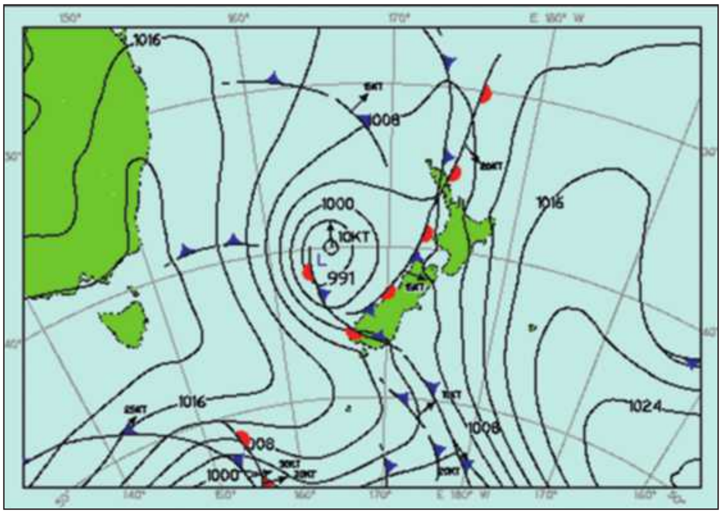


Figure 6 **A blocking high sits east of New Zealand, with a low to the west. Warm, moist air is being pulled down from the Coral Sea region and intense rain is falling in Auckland, Northland and the Waikato as the high stops air moving east but the low keeps sucking it in — flooding in Nelson has also occurred, from the same system. At this point the winds over northern New Zealand are from the northeast, but as the fronts go through they change to northwesterlies. Image reproduced courtesy of Meteorological Service of New Zealand Ltd (chart dated 1 p.m. on 15 December 2011).**

Zealand gives mainly dry weather, apart from perhaps coastal drizzle in winter (due to a humid wind moving air from sea to land) and thunderstorms inland in summer (due to intense heating of the land causing air to rise inland, sucking in humid air off the ocean). However, one to our east might keep bad weather right over the top of us; such an anticyclone is a not uncommon cause of a very cold spell (see the section on snow, below).

Anticyclones may be associated with low cloud rather than blue skies if the subsiding air can't quite reach all the way to the ground, being prevented from doing so by an air mass at ground level. In such areas the descending air spreads out at about 1 km above sea level, forming a low ceiling of warm subsiding air which the air at ground level can't get past due to the temperature inversion, usually different by 1–3°C. When the trapped air is moist, for instance when wind is blowing at low levels from the sea onto land, low cloud is likely even though at higher altitudes there are blue skies.

Both depressions and anticyclones generate wind around their edges and, as a result, swing air masses and the fronts between air masses around them also.

FRONTS AND CYCLOGENESIS

Fronts are common features of our mid-latitude weather systems which, as previously mentioned, transfer warm air from north to south and bring cold air back the other way. They represent the boundary between two air masses with different temperatures, pressures and wind direction. They develop where there is a strong thermal (temperature) gradient encouraging the passage of air (thermal advection), and require the presence of converging, opposing air currents as well as deformation of the pressure field. Cold fronts represent areas where cold air is replacing warm air, while warm fronts represent the opposite. No matter the type of front, warmer air always rises over the top of colder air.

The linear region where air is moving away from a col (the area of low pressure between two highs) is called the axis of dilation. If the temperature gradient between two air masses is roughly perpendicular to this axis of dilation (on a synoptic chart, this is shown by the isotherms being roughly parallel to the axis of dilation), then fronts will build; if the temperature gradient is more parallel to the axis, then they will subside. Perhaps the most effective situation for the formation of fronts

is when there are two subtropical anticyclones, one to the west and slightly south of the other. Fronts form to the south of the two highs, as cold air is being pushed eastwards to the south of the western high and warm air is being pushed in a southerly direction by the eastern high; the isotherms line up parallel to the axis of dilation in this area, south of the col, and a cold front is formed which will tend to then move in an easterly direction.

Areas of low pressure enhance the confluence of air — the ability of air masses to come together — whereas areas of high pressure inhibit it; this is why depressions are associated with fronts. If there is also divergence of air at upper levels with convergence at ground level, frontal development is also increased as there will be vertical ascent of air within the front.

above **A front heading east passes over Omaha Beach, Auckland.**

When a front is formed, there is often a sharp change in pressure gradient, temperature, wind speed and direction between the two air masses, giving rise to a kink on the isobaric chart.

Both cold and warm fronts are associated with cloud and rain. In a warm front, warm air overrides the cold air over a long distance (e.g. 100 km) and cloud formation occurs as the warm air is pushed up over the cold air mass. The arrival of warm air at high levels is typically heralded by the development of cirrostratus, followed by altostratus as the cloud base lowers. As the wedge of warm air

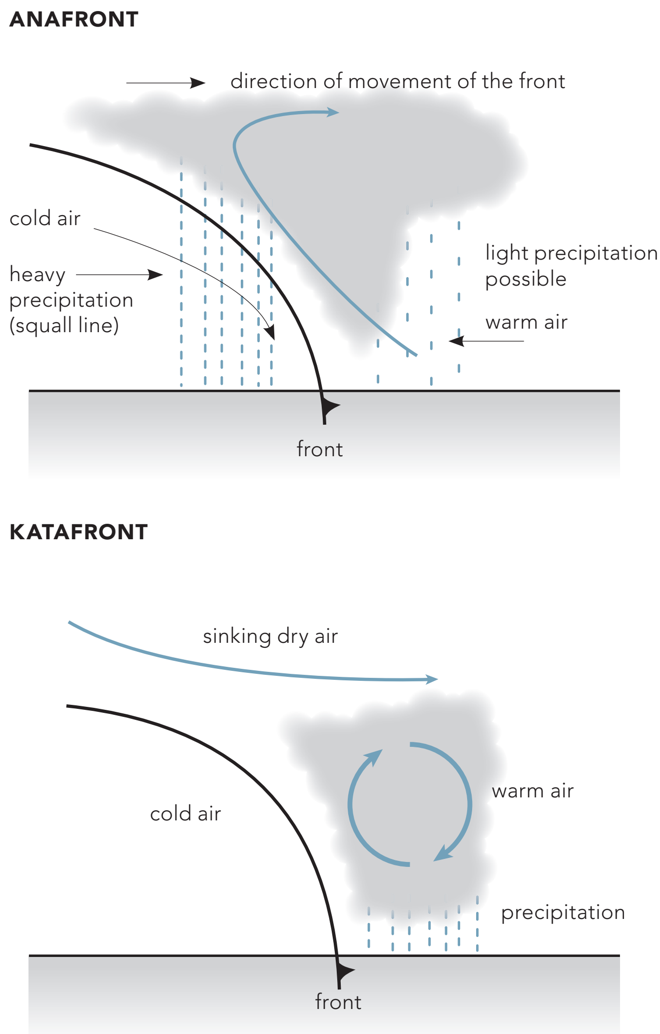


Figure 7
Anafronts and katafronts, two types of cold fronts.

continues to thicken, nimbostratus may form, with rain ahead of the front followed by a clearance as the front passes.

When a cold front approaches, the mass of cold air pushes beneath the warmer air, lifting the warm air up to form clouds and eventually rain. The vertical slope of a cold front is much steeper than that of a warm front, hence cold fronts pass overhead more quickly but the precipitation is often more intense. The ascent of the warm air slopes rearwards in an anafront, so that most of the precipitation falls after the front has passed (i.e. it is postfrontal).

There is also a second type of cold front called a katafront, where the ascent core of the warm air slopes forwards rather than over the incoming cold air mass so that any precipitation is prefrontal. This is due to dry air intruding behind the front and preventing the continued upward movement of the warm air. Development of large clouds does not occur, nor can clouds occur high in the atmosphere, so as the front moves through only smaller, lower-level stratocumulus is seen, although some rain can occur. Katafronts are thought to evolve from anafronts.

Cold fronts can also form depressions (cyclonogenesis). Because cold air is slightly denser and therefore heavier than warm air, it pushes the warmer air up at the front and

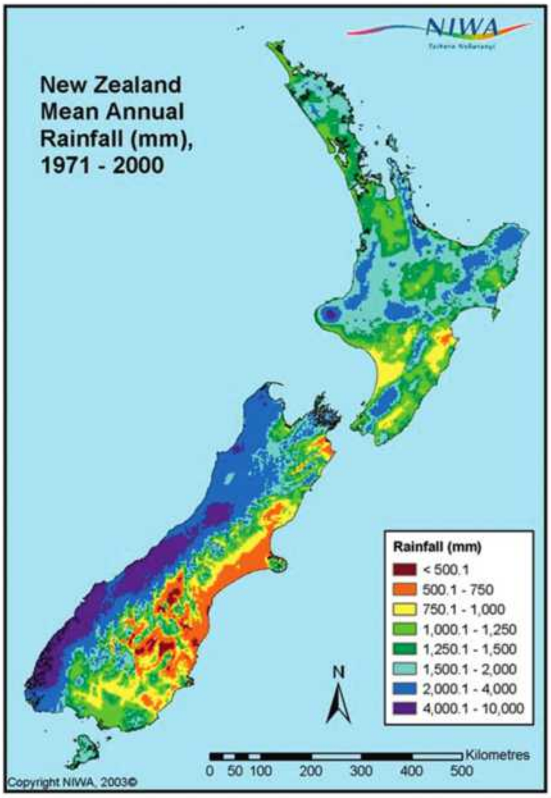
this vertical ascent leads to cloud formation. According to the frontal wave model of cyclogenesis, if this front develops a weak point (represented by a kink on the isobaric chart), air will start to converge in this area. This combination of convergence and vertical lift starts a cyclonic system (a depression) with an axis of rotation clockwise around the kink. Cold air then travels northwards on the western side of the cold front while warm air travels southwards on the eastern side, forming in its turn a warm front where the warm air pushes over the top of and displaces the cold air. In the classic textbook situation, the cold front moves faster than the warm front, eventually catching up with it and lifting the warm air pocket off the ground (an occlusion). In an occlusion, there is thus a zone of cold air in the lower atmosphere with a tongue of warm air aloft, associated with a band of cloud and rain; this marks the development of a fully mature depression. The depression then gradually decays as the air stagnates and the two air masses mix together, with the whole process from formation to decay taking about 7 days.

In practice, of course, things do not always happen exactly as they do in textbooks. A true occlusion is a rare event; meteorologists now usually use the occlusion symbol to mark a front that does not have an obvious temperature contrast but instead is marked by some other difference between the two air masses, such as humidity.

LOCAL CLIMATIC VARIATION

Clouds and precipitation vary across northern New Zealand most obviously as a result of terrain. Moist air rises when it hits ranges such as the Waitakeres or the Coromandel, cooling so that it cannot hold as much moisture; this then drops as 'orographic' rainfall, meaning that higher elevations receive more rain. Even in the relatively low-lying North Auckland Peninsula, the more low-lying areas around Auckland and the Aupouri Peninsula receive less rain than the larger bulk of Northland between Whangarei and Kaitaia, while areas of higher elevation in both regions, such as the Tutamoe and Waitakere ranges, receive more. The heights of the Hunua Ranges, for instance, receive twice as much rain as Auckland city does and, being at altitude, have a mean annual temperature 3°C lower. Conversely, the low-lying Manukau Harbour and surrounding flat lands have significantly less rain than the rest of the Auckland region.

Indeed, although the differences between climates in various parts of northern New Zealand are less than, say, those in a section across the South Island, there is sufficient land and hills to make some places quite significantly different from others — not for nothing is Mt Maunganui better known than Raglan for sunbathing. As the prevailing winds are from the west, generally the west is wetter and rainfall is reduced in the east, particularly in the lee of ranges such as the Kaimai Range which protects the Bay of Plenty, and the Raukumara Range which protects the Gisborne District; but even locals on Waiheke Island will comment how much drier that low-lying eastern island is compared with Auckland city



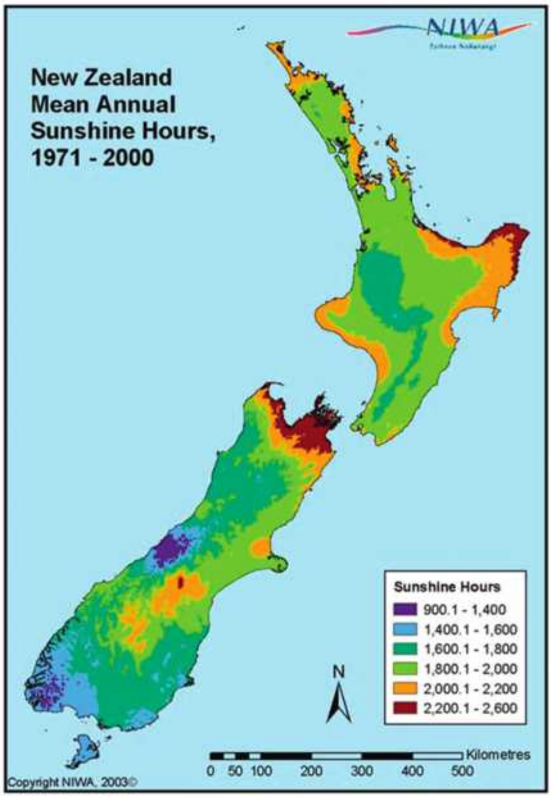


Figure 8 **Mean annual rainfall, 1971–2000. Notice how low-lying areas, such as the Aupouri Peninsula and the Waikato basins, and areas such as Taupo that, even though they are at altitude, are surrounded by higher land, have lower rainfall. Poverty Bay is our driest area because it is in the lee of high hills facing east, away from the prevailing westerly winds, although the higher land around it does have a greater rainfall. The coastal Bay of Plenty is also relatively sheltered, with ranges on all sides bar the generally more clement north. The west-to-east difference in rainfall is much more pronounced in the South Island where the barrier to the westerly winds, the Southern Alps, is much higher. Image reproduced courtesy of NIWA, 2003.**

Figure 9 **Mean sunshine hours, 1971–2000. Sunshine hours are approximately the reverse of rainfall, as one would expect, with the exception that higher elevations are not always much more cloudy than those lower down. In particular, note that the Raukumara Peninsula (East Cape area) is sunnier than its rainfall would suggest, as it gets relatively larger downpours with orographic rainfall for the same amount of cloud cover. Nevertheless, isolated peaks such as Little Barrier Island and Mt Te Aroha are still more often shrouded in cloud than the lowlands or sea around them, due to orographic lift and subsequent condensation. The more mountainous and southerly South Island, again, has greater extremes. Image reproduced courtesy of NIWA, 2003.**

centre. The most dramatic contrast, surely, is the sudden change from dense bush to brown hills as one crests the Raukumara Range on the journey from Opotiki to Gisborne. On the Opotiki side of the range, prevailing westerly winds drive the air up the sides of the hills to cause orographic rainfall. As the air then descends on the Gisborne side, it warms so can hold more water, making clouds and rain less likely to occur (see Fig. 4). The axial Raukumara Range is sufficiently high that these northwest foehn winds coming across them, although on a more mild scale than those of Canterbury, are enough to have produced the North Island's maximum temperature (39.2°C at Ruatoria on 7 February 1973) as well as an obvious difference in vegetation, thanks to the decreased rainfall. In easterly winds, Port Taharoa on the southern Waikato coast can record a very high temperature because of the same mechanism; but, of course, our prevailing

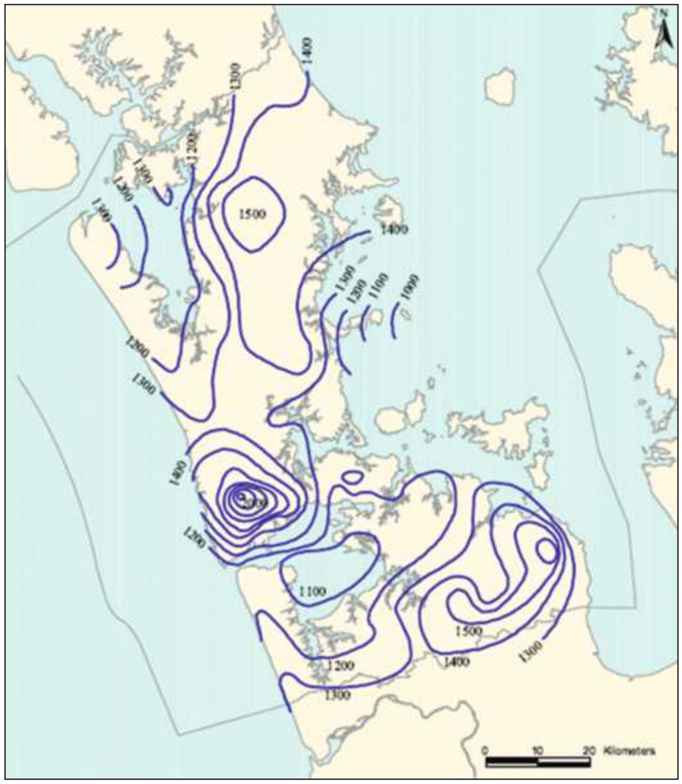


Figure 10 **Variation in mean annual precipitation (as measured in mm per year) in just one region, Auckland, 1980–1997. Note how the higher elevations of the Waitakere and Hunua ranges (on the west and the east, respectively), the Hoteo catchment in the north and even One Tree Hill on the isthmus, receive more rainfall. There is a corresponding decrease over the low-lying Hauraki Gulf, Kaipara and Manukau harbours. Note how some areas have twice as much rain as others! Image reproduced courtesy of Auckland Regional Council, 2002. *Auckland water resource quantity statement 2002*, TP171, p.6**

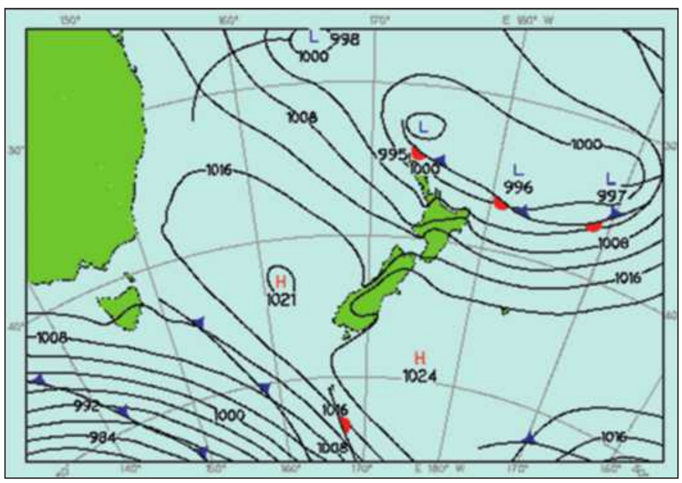


Figure 11 **Very strong southeast winds with heavy rain in the windward Gisborne, Hawkes Bay and Coromandel areas. On the leeward coast, the temperature reached 26.4°C in Port Taharoa near Kawhia, due to a foehn effect; it was 24.8°C in parts of Auckland, which was experiencing cloud with rain expected later. Image reproduced courtesy of the Meteorological Service of New Zealand Ltd (chart dated 6 a.m. on 4 April 2012).**

wind is from the west so the east coast in general has a 'better' climate than the west.

It would be reasonable to assume, of course, that those areas in the lee of ranges and hence sheltered from the prevailing winds are also likely to be less windy. However, this is not necessarily the case; the northwest winds of Canterbury to our south can be very strong. In the north, Te Aroha can experience severe winds during easterlies; air builds up east of the Kaimai Range, then spills over and rushes down the western slopes even more intensely where it is squeezed through valleys. The high winds can be extremely localised in these situations. The Kaimai Range not only shelters Tauranga from the west, from where the majority of our rain-bearing frontal systems come, but it also blocks moderating

coastal sea breezes present in the Bay of Plenty, leading to stiller but frostier conditions in the Waikato.

Rain can occur also when a southerly comes up the east coast of the North Island and spills into the Bay of Plenty as an easterly; heavy rain affects the Bay and there are lighter showers in Auckland. This aside, with the obvious exception of Gisborne District we are generally more protected from the southerly than other parts of the country by the high land in the centre of the North Island; Mt Ruapehu can split the clouds either side of it in a southerly, giving clear air over the Waikato. The larger landmass of the Southern Alps can also split the clouds around it; if the wind is coming from slightly south of south-west, then we are in the lee of this barrier and fine weather predominates, with the exception of Northland which sticks out on an angle

above **Northwest 'arch' clouds forming, at Gisborne Airport on 31 January 2010, with rainclouds visible over the axial ranges further inland. See Figure 4 for a graphical explanation of this foehn-type event. Gisborne District.**

to the northwest. Nevertheless, a decent southerly can still bring a precipitous drop in temperature and heavy rain, often followed by clear, cold weather with frosts in spring and autumn as well as winter.

Sea breezes moving inland may cause cumulus cloud to form, sometimes enough to cause showers, as they are pushed up by the heating land and as they converge with air masses already there. Showers are more likely if they meet with sea breezes coming from the other direction (sea breeze convergence), as can happen in the Raukumara Range (sea breezes off the Bay of Plenty meet those off the east coast) and Auckland (from the opposing

Waitemata and Manukau harbours). Also, when air comes ashore it slows down due to friction from the ground; this 'convergence' of air increases the pressure, forcing the air to go up and generating lift. Inland locations such as Hamilton are generally less windy, as they are protected from sea breezes.

above **Snow in Epsom, Auckland, 15 August 2011. Photograph: Lisa Hoskin.**

OTHER LOCAL WIND TYPES

KATABATIC AND ANABATIC WINDS

During the day, air close to a slope will be warmed by the ground it is next to more than air at the same level but further from the slope, and will be cooled during the night due to the land cooling down next to it. As a result, it will become lighter during the day and heavier during the night than the rest of the air, forcing it to move either uphill or downhill. Hence, during the day one can encounter a wind blowing up a valley and, at night, one blowing down from the tops. These are respectively termed anabatic and katabatic winds and usually occur on a local scale, although in Antarctica, with its huge ice dome, katabatic winds are formed by the slope of that dome and are hence continental in scale!

DOWNSLOPE WINDS

At the edge of an escarpment, a wind similar to a katabatic wind blowing down off the top of the ridge can be caused by the general wind direction pushing a cold mass of air off the summit and down into the lowlands below.

SNOW

Snow is not common in northern New Zealand at the altitude most of us live, although not quite as rare as some might imagine — snow has been recorded lying on the ground on several occasions in Auckland city since European settlement began; there was snow even on Cape Maria van Diemen in July 1939. Most recently, Auckland experienced snow settling in the CBD, albeit briefly, on 15 August 2011, although this was the first time in decades. Snow is quite common in the higher axial ranges and on isolated summits such as Mounts Pureora and Tarawera; on the Raukumara and Urewera ranges snow can sometimes be seen well outside winter. Every few years snow also comes to lie on the higher peaks of the Coromandel and on Mt Te Aroha and Mt Pirongia.

To cause snow, the air must be cold and this means that it has to come from very close

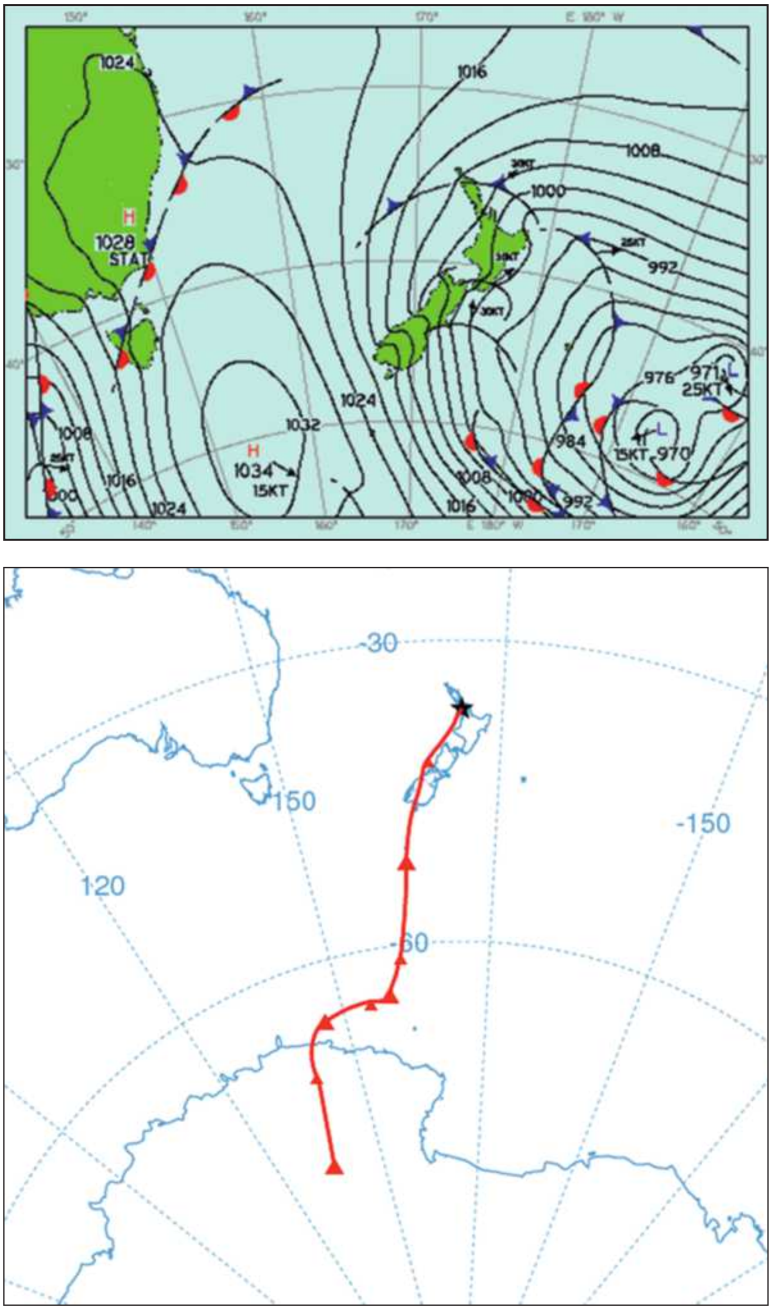


Figure 12 **Weather maps: 15 August 2011, at noon — the day it snowed in Auckland city (just after 2 p.m.). There are closely spaced isobars over the whole country, coming from the southwest in northern New Zealand after having been refracted lightly by the Southern Alps (top); the backward trajectory of the air at 500 m arriving in Auckland at that time shows that it arrived almost directly from Antarctica; triangles denote the location of the air mass at 12-hourly intervals (bottom). The wind is being driven between a low to our southeast and a high to our southwest, with a cold front concurrently moving over Northland. More snow fell in the west (e.g. the Kaipara District) than in the east, as the west was to windward. Images reproduced courtesy of the Meteorological Service of New Zealand Ltd (above and left) and the NOAA Air Resources Laboratory (left).**

to Antarctica; in August 2011 there was a high southwest of New Zealand and a low to the southeast, directing the isobars straight up the country directly from Antarctica (Fig. 12). However, cold weather and snow does not always arrive at our latitude directly from the south. Earlier in the same year (July 2011), sleet was reported in Auckland's Waitakere Ranges; this was the result of air being sucked up by a trough that was stationary over New Zealand pulling cold air up from the very edge of Antarctica to Tasmania, which then turned east to come across to us via the prevailing westerlies.

In winter, of course, snow and cold weather is much more common; not only are

temperatures lower but there is also more pack ice covering the seas around Antarctica, so that an air mass coming from there has a much shorter sea journey to warm it up before it hits us. However, sometimes it can be colder in months such as May and October than in August — this was certainly the case in 2009. The reason being, the average location of the highs and the lows: in May and October that year, there was, on average, a trough lying over New Zealand, wedged between highs over southern Australia and well to the east of the Chatham Islands; whereas in August there was a northwest flow over us, driven by a high east off East Cape.

TEMPERATURE

In general, the further south and the higher one goes in our region, the lower the average annual temperature. These factors work in combination, as heading south generally involves gaining altitude towards the Central Plateau. In general in New Zealand, there is a drop of 10°C for each 1000 m of altitude gained in dry conditions and 6°C per 1000 m in moist conditions, for reasons described previously. For instance, the summit of Mt Te Aroha (at an altitude of 950 m) has a mean annual temperature of 8°C, vs 15.4°C in the town below (at 30 m). The diurnal temperature range on hills is also less than the usual coastal 9°C, because of cloudiness (at Te Hunga, altitude 600 m, in a 17-day stretch of fog the mean diurnal temperature range was recorded as 2.5°C).

Temperatures also affect plant growth; growing degree days — a measure of the amount of heat accumulated during periods when the thermometer measures more than 10°C — are commonly used to estimate the effect of temperature on plant growth. Again using Te Aroha as an example, the town has been quoted as having 1727 growing degree days with a growing season that extends from September to May; at the summit, although its temperatures are similar to those in Invercargill (which has 514 growing degree days) it also has 200 days of fog (vs 20 in the town), which reduces photosynthesis very substantially, by approximately 75%. During

Figure 13 **Meteorological observations at different places in northern New Zealand. Chart reproduced courtesy of NIWA.**

	RAIN-FALL	WET DAYS	SUN-SHINE	MEAN TEMP.	HIGHEST TEMP.	LOWEST TEMP.	GROUND FROST
	MM	>= 1MM	HOURS	CELSIUS	CELSIUS	CELSIUS	DAYS
KAITAIA	1334	134	2070	15.7	30.2	0.9	1
WHANGAREI	1490	132	1973	15.5	30.8	-0.1	11
AUCKLAND	1240	137	2060	15.1	30.5	-2.5	10
TAURANGA	1198	111	2260	14.5	33.7	-5.3	42
HAMILTON	1190	129	2009	13.7	34.7	-9.9	63
ROTORUA	1401	117	2117	12.8	31.5	-5.2	57
GISBORNE	1051	110	2180	14.3	38.1	-5.3	33
TAUPO	1102	116	1965	11.9	33.0	-6.3	69

the relatively wet summer of 1968/69, the summit was recorded as having fewer than 120 growing degree days. The growing season probably only lasts from December to March and hence it must be an extremely difficult climate for plants, which also have to cope with waterlogged soil.

However, to confuse the issue, the larger landmass encountered as one moves further south and away from maritime influences also produces a slightly more continental climate with greater extremes; this combination ensures that winters in Hamilton are much frostier than those in Auckland, only 104 km to the north. Our most continental climatic region is probably the southern Kaingaroa Plateau, which has hot summer days and cold nights; the cold air pools in the lower points at night, hence the 'frost flat' vegetation. The inland centres of Hamilton and even Taupo (4 hours' drive south of Auckland; Lake Taupo, on which the town is centred, is at an altitude of 356 m) have all also recorded higher temperatures than Auckland or anywhere in Northland, because of the decreased maritime influence; for instance, on 29 January 2013, when a large high was situated over New Zealand giving us all next-to-perfect summer weather, the forecast high in Whangarei was 25°C and that in Auckland 26°C, but in Hamilton it was 29°C and for Taumarunui, further south but inland and at a relatively low altitude, it was 32°C. Ruatoria in the northern Gisborne District has recorded the highest temperatures in the North Island, due to the northwest foehn wind.

Figure 14 **Mean surface temperatures, 1971–2000. Note the general trend for warmer temperatures at lower altitudes and latitudes. Image reproduced courtesy of NIWA.**

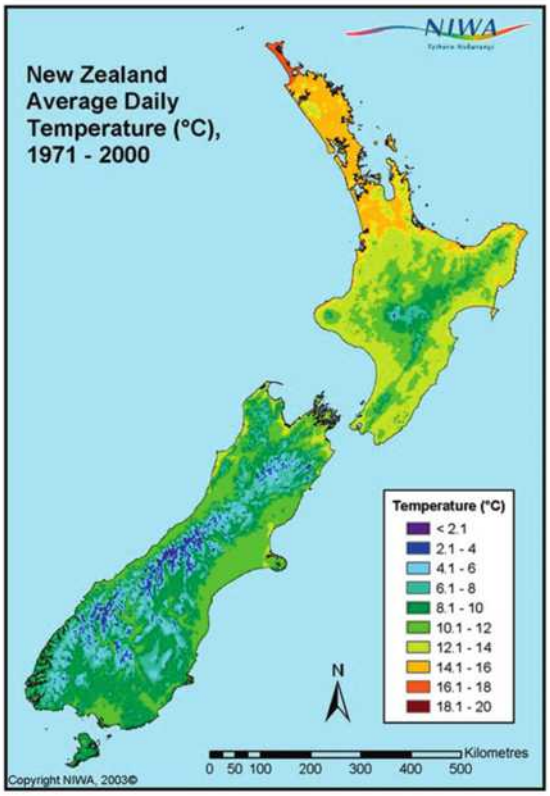


Figure 15 **Mean monthly temperatures, 1981–2010. Chart reproduced courtesy of NIWA.**

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
KAITAIA	19.7	20.0	18.6	16.9	14.8	12.7	12.2	12.1	13.1	14.5	15.8	17.9	15.7
WHANGAREI	19.9	20.0	19.0	16.5	14.0	12.2	11.2	11.7	12.9	14.3	16.4	18.2	15.5
AUCKLAND	19.3	19.8	18.5	16.2	13.7	11.6	10.8	11.3	12.6	14.1	15.8	17.8	15.1
TAURANGA	19.2	19.2	17.9	15.4	12.5	10.4	9.7	10.5	12.1	13.6	15.6	17.5	14.5
HAMILTON	18.3	18.7	17.1	14.5	11.6	9.4	8.7	9.8	11.4	13.1	15.0	16.8	13.7
ROTORUA	17.8	17.9	16.4	13.5	10.5	8.4	7.6	8.7	10.4	12.3	14.3	16.1	12.8
GISBORNE	19.2	18.9	17.4	14.8	12.0	10.0	9.3	10.2	11.8	13.8	15.9	17.8	14.3
TAUPO	17.4	17.5	15.6	12.5	9.6	7.6	6.7	7.6	9.4	11.5	13.6	15.7	11.9

HUMIDITY

Humidity is the other part of our weather that the visitor from the south is sure to comment on, especially in summer by the northern coast when there can be a period of several days of warm humid air coming down from the subtropics and we all complain of being unable to sleep. Northern New Zealand is actually not necessarily that much more humid than other places; humidity is a relative measurement, measuring the amount of moisture in the air compared with what the air can hold; but since warmer air is capable of holding more water than colder air, at the same humidity our warmer air does carry more moisture. This is particularly so when very warm and very moist subtropical air arrives in midsummer; sometimes sufficient water is carried in this air as to cause widespread fog as it hits our slightly cooler shores.

TORNADOES AND MICROBURSTS

Tornadoes can also occur, particularly in our west, although they are rare and are never on the same scale as in 'Tornado Alley' in the United States. They develop as a result of a mesocyclone, a local (over about 3–15 km) vortex of air within a convective storm, with rising air rotating around a vertical axis. In a tornado that started in Albany in Auckland on 3 May 2011, the rising air was caused by a line of convergence (northeasterlies and northwesterlies that were being pushed into each other) lifting the air up as a front went through — a common cause also of thunderstorms, which were also present in the area at that time. Local geography then imparted a twist to this rising air, creating a tornado; given that local geography does play a role in tornado formation, it can be assumed that tornadoes are more likely to occur in places where they have occurred previously than in others.

More commonly, New Zealand experiences tornadoes as a result of convection along a strong cold front (hence, they tend to be a 'cold season' phenomenon); such a scenario produced the Avondale (Auckland) tornado of 11 September 2011. Some waterspouts are also tornadic in nature but most are not associated with a rotating updraught in a thunderstorm. Instead, fair-weather waterspouts occur in association with non-frontal, stationary developing cumulus towers with a vertical convective updraught in coastal waters.

A tornado was initially blamed for the intense, sudden and very localised winds that killed three people in Hobsonville, Auckland on 6 December 2012; later in the day, as the cold trough moved east, another tornado was reportedly observed in Ngongotaha near Rotorua. However, it was probably a 'microburst', a localised wind event. This event was caused when a cold front (trough) with showers approached from the west, with northeasterlies in front of it and northwesterlies behind which pushed against each other, causing a line of convergence. The front and the convergence lifted the warm, unstable and humid air mass that was present ahead of the front, causing further instability and thunderstorms. The localised wind storm probably resulted from a collapse of one of these thunderstorms.

FLOODING AND THE TIDES

Flooding can occur in very high tides. On Sunday 23 January 2011, a 'double hit' caused flooding in Auckland, with water spilling over both Tamaki Drive and the Northwestern Motorway. There was a predicted high tide of 3.5 m because of it being a perigean spring tide (a 'king' tide, due to either a full or new moon coinciding with the moon's closest approach to the Earth); the tide was also higher than normal due to it occurring in a La Niña cycle

(see below). On top of this, a low-pressure system (the remnants of a tropical cyclone) caused the water level to be an extra 10–12 cm higher again and strong winds from the northeast pushed the water onto the roads.

The tides vary around our region. Mean high water spring (MHWS) tides on the East Coast and the Bay of Plenty, for instance, are around 2 m. Onehunga and Thames, on the other hand, regularly have 4+ m MHWS tides because they are at the top end of a bay (compare the coastal Waikato River entrance's MHWS tide of 3.7 m with Onehunga's 4.2 m). Generally, the tides are highest in our southwest and lowest in our southeast (i.e. at Gisborne). Tides rotate around New Zealand twice each day in a clockwise direction (New Zealand is termed a 'node' in this regard).

EL NIÑO AND LA NIÑA

El Niño, 'the Christ Child', was first noted on the west coast of South America at Christmas time, hence the Spanish name. Normally there is an upwelling of cold, nutrient-rich water along that coast, resulting in excellent fishing. However, every few years the fishing turned very poor; this coincided with a warming of the sea surface. These years were termed El Niño years.

Warm oceanic surface water is separated from the colder, deeper water by a zone of rapid vertical temperature change known as the thermocline. In the Pacific, this is typically deeper at the western (Australian) end and shallower at the eastern (South American) end. In a normal year, the water in the western Pacific is warmer and the sea level higher than in the east. The higher sea level is caused by persistent easterlies, the trade winds, pushing the water towards the west in the tropics. This 'Walker circulation' allows the aforementioned updwelling of nutrient-rich cold water to reach the ocean surface off the coast of Peru and Ecuador.

However, if the easterlies fail, then the warm surface water will slide in pulses downhill to the eastern Pacific over a front many kilometres wide, although perhaps only a metre or two thick on the ocean surface, taking some 3 months to cross the Pacific. This has the effect of deepening the surface layer of warm ocean adjacent to South America; thus, when offshore winds cause upwelling of deeper water, the deeper water is still warm (and depleted of nutrients; hence, the poor fishing). This changes the weather throughout the Pacific and is the cause of an El Niño year. The difference in sea level and barometric pressure between the western and the eastern Pacific (as measured between Darwin and Tahiti) is also called the Southern Oscillation, hence the acronym ENSO, short for El Niño Southern Oscillation.

In an El Niño year, there is an increase in the prevailing southwesterlies over New Zealand. Lying as they do in the lee of the rest of the country, northern and eastern areas become drier during such an event. La Niña ('the girl'), in contrast, represents an accentuation of the normal pattern and we get affected by more weather coming from the north and east, causing warm, muggy and humid conditions. However, ENSO only accounts for at most up to a quarter of normal year-to-year climatic variability.

A cause of climatic oscillation over decades has also been found: the Pacific Decadal Oscillation; in California, this weather pattern led to relatively benign weather from about 1945 to 1977, when houses were built on erosion-prone coastlines. When there was a later change to a stormier pattern, erosion increased with significant property damage as a result.

UV RADIATION

New Zealand has one of the highest incidences in the world of cutaneous melanoma, due to our climate, lifestyle and predominantly light-skinned population. Hence, one climatic datum we are often confronted with is the UV (ultraviolet) index: the higher the index, the more we need to 'slip, slop, slap'. Although the amount of radiation in the north lessens in winter, it does not do so as dramatically as further south; summers in the south expose one to as much UV radiation as in the north because the longer days make up for the greater angle of incidence of the rays of the Sun on the Earth at higher latitudes, but in winter the days are shorter and the Sun's rays are at an even more acute angle, with these two factors combining to reduce UV radiation dramatically. Comparatively, therefore, the north has a relatively high winter level of solar radiation. Our ozone level is also lowest in summer and autumn, when the UV index is higher, contributing to our high rate of skin cancer. Unfortunately, our relatively cool summer weather often leads people to bask in the sun when it is at its most dangerous, unlike in many parts of Australia where people are forced to seek shade in the middle of the day to escape the more intense heat. Over the last few decades there has been a slow decline in ozone levels over New Zealand and Australia, and an ozone hole has developed over Antarctica in spring from the late 1970s; it is hoped that global reduction in the use of the ozone-depleting chemicals chlorofluorocarbons (CFCs) and halons will alleviate this problem.

The Earth is closer to the Sun in the Southern Hemisphere summer (since the Earth's orbit is elliptical rather than circular) than in the Northern Hemisphere summer. This causes Southern Hemisphere sunlight to be around 7% more intense in summer than in the Northern summer.

Figure 16 **Mean daily global radiation (megajoules/square metre), 1981–2010. Chart reproduced courtesy of NIWA.**

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
KAITAIA	21.7	19.4	16.4	11.6	8.5	7.0	7.7	10.1	13.5	16.9	19.9	22.1	14.6
WHANGAREI	20.8	18.4	15.5	11.3	8.4	7.1	7.4	10.3	13.7	16.9	18.8	20.4	13.8
AUCKLAND	23.1	20.1	16.0	11.7	8.3	6.6	7.9	10.0	13.8	17.5	20.9	23.1	15.0
HAMILTON	21.7	19.2	15.8	11.1	7.7	6.2	6.7	9.0	12.7	15.9	19.9	22.0	14.1
TAURANGA	23.0	20.2	16.4	11.4	8.1	7.0	7.1	9.8	13.7	17.2	20.4	22.6	14.6
ROTORUA	22.5	19.6	16.0	11.1	8.0	6.3	6.7	9.4	12.9	16.6	19.5	21.6	14.1
GISBORNE	22.6	19.4	15.4	10.8	7.9	6.6	6.8	10.0	13.9	18.5	20.7	23.0	14.6

GLOBAL WARMING

One of the greatest threats to the stability of our weather is global warming, the effects of which we are beginning to see as a result of increased carbon dioxide in the atmosphere, created by the burning of fossil fuels, which traps heat in the atmosphere. The changes that it will create, because of altered weather patterns and increasing sea levels due to melting of land-based ice and thermal expansion of the oceans, may even threaten our current global civilisation.

In general, with warming of the planet there will be increased turbulence in the atmosphere (more energy, more storms), leading to greater storminess and other unusual weather events, and increased evaporation, leading to increased precipitation. Conversely, our summers — already relatively dry due to the southerly movement of the high-pressure zone — during this season, may become drier.

Hence, it is thought that the effect of global warming will be to accentuate the current climatic variations: the drier parts will become drier, the summer droughts in the north more severe, and the wetter parts will probably get wetter. Our winters, in other words, will still be wet! Increasing atmospheric temperatures will allow more tropical species to be able to survive over winter and reproduce here, while we may lose those species that survive only in our coldest parts. Many pest species being of a more tropical provenance, we are likely to have to cope with more such invaders.

above **Drought, March 2013, near Miranda, Waikato District. Droughts such as this, one of the worst ever on record in northern New Zealand, are likely to become more common with climate change.**

SUMMARY

In general, we have a mild, maritime temperate climate that allows outdoor activities in every season, except perhaps when it's raining, which is not uncommon. The air that bathes us is usually temperate, although our location in the middle latitudes means that we can get occasional outbreaks, lasting a few days, of both tropical and polar air. Our position in the middle of an ocean as well as the presence of Antarctica in our hemisphere combine to markedly reduce seasonality when compared with other countries at a similar latitude.

Nevertheless, summer tends to have the most settled weather with the least rain, with winters being the opposite. In summertime the southernmost part of the subtropical Hadley Cell is not too far away, bringing drier temperatures; but even summers can be quite variable, depending on tropical cyclones and El Niño. Summers are reasonably warm but not uncomfortably hot, with maxima between 21°C and 26°C and seldom exceeding 30°C west of the Raukumara Range; in Gisborne District, daytime summer temperatures range from 20°C to 28°C and can rise above 30°C, particularly with the strong northwesterly foehn winds. The mildest winters are experienced in Northland, Auckland, the Coromandel and the coastal Bay of Plenty, which face the northern seas, with maximum air temperatures ranging from 12°C to 17°C; further south and inland in the Waikato, Taupo and Rotorua winters are cooler, with maxima ranging from 10°C to 14°C and frosts common on calm, clear winter nights; in winter, Gisborne can be a little warmer with maxima between 10°C and 16°C.

Southwesterlies are our prevailing winds, changing to westerlies and northwesterlies interspersed with southerlies east of the axial ranges, with sea breezes on warm summer days; Rotorua and Taupo experience 'lake' breezes' akin to these sea breezes. In summer and autumn, Northland through to the coastal Bay of Plenty more often experience storms of tropical origin with high winds and heavy rainfall from the east or northeast. The inland areas of Taupo, Rotorua and the Waikato tend to be less windy due to sheltering ranges to the east and south.

Rainfall in northern New Zealand is generally very adequate, although we can be affected by drought in summer. Rainfall is slightly higher in Northland and the Waikato than in the generally lower-lying Auckland, and significantly higher in the west and on higher elevations, such as in western Northland and the Coromandel, Kaimai and Raukumara ranges. It is less in the Bay of Plenty, in the lee of the Kaimai Range, and least in Gisborne, which is to the east of the largest range, the Raukumara.

These lee areas (i.e. the Bay of Plenty and Gisborne) are also the sunniest areas of our region, with 2200 or more hours per year of sunshine, although most lowland areas receive around 2000 hours. The eastern Bay of Plenty usually edges out Gisborne in the sunshine stakes due to Gisborne's exposure to the southerly in winter; Whakatane even took the title of New Zealand's sunniest town in 2010, a title usually shared between the South Island's Nelson and Blenheim. We have a particularly high rate of cutaneous melanoma, and protection from UV rays in summer is essential, even when it doesn't feel that warm.

However, we are perhaps less aware of the large amount of land that lies at altitude, as human settlement is concentrated almost exclusively in the lowland zone. At altitude the weather can be quite different: temperatures are distinctly lower and winds are stronger, while cloudiness and precipitation increase. The least sunny are the highest areas (the axial ranges and the Central Plateau), particularly on their western aspects.

CHAPTER FOUR:

A BRIEF HISTORY OF OUR FLORA AND FAUNA

INTRODUCTION

Before we move on to discuss our present-day flora and fauna, it is useful to consider where everything came from. The development of our current native communities has been shaped by our changing geology and position in the world, immigrants both ancient and modern, and animals only recently extinct.

DINOSAURS AND OTHER MESOZOIC FOSSILS

Our geological history starts in the Palaeozoic, but it was in the Mesozoic that most of our basement rock was formed — and the Mesozoic was famous for one group of reptiles in particular, the dinosaurs. In the far southeastern corner of northern New Zealand is the Mangahouanga Stream (in the Te Hoe valley, Hawke's Bay Region), a site from the Cretaceous period. Although no complete skeletons have been discovered — it is more a case of occasional bones — enough has been found to identify a 9 m allosaur, as well as a smaller carnivorous dinosaur, a herbivorous hypsilophodont, the massive titanosaur, and the armoured ankylosaur. Dinosaurs are not just an interesting but extinct footnote in vertebrate history; birds evolved from therapod dinosaurs in the late Jurassic, around 140 million years ago (Ma), the most famous 'missing link' being *Archaeopteryx*, found in southern Germany.

Non-dinosaur fossils have also been found in the Mangahouanga Stream, including a pterosaur, a cockroach, a beetle and a turtle as well as a marine reptile, the plesiosaur; this was a coastal location at the time of its formation, so both the remains of land animals, washed down into the sea, and those of marine creatures are present. Other marine reptiles, ichthyosaurs, have been found near Dargaville, Waitomo and Kawhia, and there has been one dinosaur bone found at Port Waikato. The western Waikato Murihiku sediments also contain invertebrate fossils, and those from Port Waikato contain fossil plants, including *Pentoxylon*, probably a floppy, flexible shrub, from the Jurassic and early Cretaceous.

above **A model of a fossil ammonite found near Kawhia, Waikato District. Built in 1989 by Ann and Alistair Stubbs (Waitomo Cave Museum Society). Image reproduced courtesy of the Waitomo Museum of Caves.**

Although nowhere in New Zealand can we find an intact *Tyrannosaurus rex* skeleton, compared with the rest of the country northern New Zealand is dinosaur-rich. New Zealand's oldest beetle fossil is also from northern New Zealand: a 145-million-year-old wing case collected near Port Waikato.

Around Kawhia, in Jurassic Murihiku rocks, one can find invertebrate fossils such as the

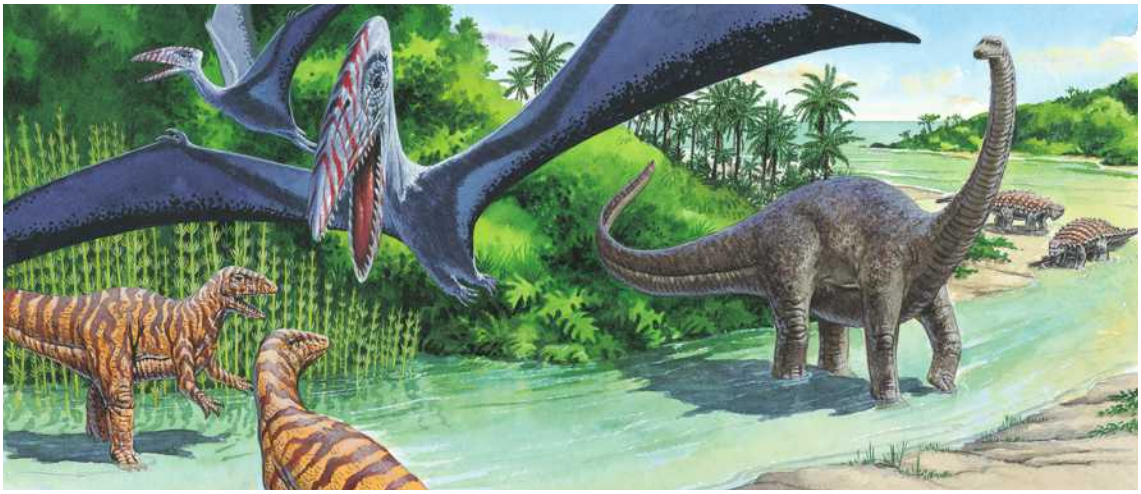
above **Belemnite, found by Lucy Hadden in Kawhia Harbour, Waitomo District.**

cephalopod ammonites and belemnites which date from the Jurassic. The largest ammonite fossil found there to date is 1.52 m in diameter, but despite their bulk ammonites have not left any descendants. Belemnites, on the other hand, were probably the ancestors of squid and cuttlefish and their fossils — or rather, fossils of the hard 'guard' part of the animal — are also very common there. The largest belemnite fossil from Port Waikato is such a guard and measures 113 mm long; this indicates that the animal it came from was probably 1.2 m long. A guard fossil found in Indonesia may have been from an animal 4.5 m long.

Zealandia finally separated from Gondwana around 83 Ma, in the Cretaceous, carrying with it a cargo that contained some plants and animals recognisable today. These include the ancestors of trees such as kauri (*Agathis australis*, our most ancient lineage and a type of araucarian pine) and the almost-as-ancient podocarps (e.g. rimu and totara), as well as animals such as tuatara, weta, peripatus and New Zealand frogs, which were common in the rest of Gondwana at that time. Ferns and mosses throve under this coniferous canopy, although grasses were not yet present.

Just before separation, perhaps 100 Ma, angiosperms started to emerge and are now dominant over much of the planet's land surface. Angiosperms have a relatively more efficient reproductive system than conifers, the flower, which can be pollinated by wind, insects or even by itself. The most common large angiosperms are our southern beeches, but they also include such humble plants as the grasses and manuka. The beeches (Nothofagacae) are particularly interesting as they extend around the former Gondwana to Australia, New Guinea, New Caledonia and South America; there are also fossil beeches in Antarctica, although not Africa or Madagascar. Beeches and some other angiosperms, including members of the *Fuchsia*, *Protea* and *Magnolia* genera which accompanied them, are poorly suited to long-distance dispersal; for instance, beech hasn't managed to recolonise Great Barrier, 18 km from the nearest seed source, or Stewart Island (32 km away from the South Island). Yet, at the time of their dispersal, Zealandia may have already separated from Australia. Presumably, therefore, there was still a link to South America, via connections with Antarctica; the widespread provenance of the beeches is an excellent argument for once-contiguous landmasses. The similarities between our beech forests and those of southern South America are uncanny, not only in outward appearance — they even share the same parasitic fungi, mosses and flightless bugs that suck their sap.

However, angiosperms never came to dominate our lowland forests as they did in temperate Eurasia, North America and even Australia (the eucalypts are an angiosperm). Instead, we were lucky enough to have been left with a diverse range of gymnosperm forests, at least until the invasion of man.



AFTER THE DINOSAURS

Although dinosaurs became extinct, their descendants the birds became the masters of New Zealand, along with reptiles such as the tuatara, skinks and geckos and a diverse range of invertebrates. A few mammals reached our shores, including three species of bat and the marine mammals such as New Zealand fur seals (*Arctocephalus forsteri*) that haul up on our coastline, but it is thought we escaped mammalian dominance because we separated from Australia and Antarctica before the advent of mammals in the Cenozoic. A recently primitive mammal tooth found in Central Otago, dating to more than 15 Ma, is now thought to be that of a bat. How many animals actually survived the Oligocene immersion and how many of our native species arrived here after this date is a matter of debate. The question has also arisen as to how much of New Zealand, if any, stayed above water at that time. At present, the biogeographical and geological evidence suggest very strongly that some of Zealandia's landmass never entirely went away. This evidence includes the following.

- Geological: our Oligocene limestones are less pure than oceanic limestones (for instance those found in the Bahamas and the Maldives), as they have some terrigenous input. Geological evidence in northern New Zealand includes coal deposits in the King Country in which, although there is a gap in the record (due to a cessation in drilling), the plant species both before and after the supposed drowning are very similar and hence imply continuity.

- Biogeographical: not only do we have many distinctive animals, but fossils of these have never been found anywhere else (e.g. moa, kiwi, wrens, native frogs, large parrots and wattlebirds). Some invertebrates, including jaw moths, land snails, stick insects and moss bugs,

above **New Zealand in the Cretaceous. We now know that dinosaurs and flying reptiles inhabited Zealandia, alongside the ancestors of our current plants and animals. Pictured here are, from left to right, carnivorous therapods, flying pterosaurs, a sauropod and armoured ankylosaurs. Illustration by Dave Gunson, from *Lost Worlds of Aotearoa* (Random House).**

don't move much; and in particular, molecular dating puts the divergence of the koura from Australian species at 109–160 Ma. The entire lifecycle of the koura requires freshwater, and freshwater means dry land.

- The strongest evidence of all comes from the deep south. A fossilised shoreline has been found at Kokonga in Central Otago. Nanofossils and strontium isotopes have identified other Otago and Southland shorelines present during the Maximum Marine Inundation (MMI), in the Oligocene, as well as wood and other fossils indicating extensive forests, swamps, estuaries and possibly mangroves. Lake Manuherikia, which once existed where Saint Bathans is now, has left fossils of freshwater crocodiles, frogs, a turtle and even a terrestrial mammal that date from just after the supposed drowning, as well as our other famous endemics — could they all have reached here so quickly after the drowning?

- There are many other distinctive species unique to New Zealand, both plant and animal, ranging from matai, tanekaha and kauri to kokako and geckos. That said, we also recognise that the majority of our biota has arrived since the Oligocene, mostly from Australia.

In summary, there is very good evidence that there was land at the time of the MMI, in the deep south (Central Otago, the Catlins, Fiordland and probably Stewart Island), in other parts of the country (northwest Nelson) and even in northern New Zealand (the King Country and Northland).

It is interesting to note that although bats can clearly fly to New Zealand — the long-tailed bat (*Chalinolobus tuberculatus*) almost certainly came here relatively recently from Australia — the short-tailed bat (*Mystacina tuberculata*) has a very ancient lineage and may have arrived here very early on, possibly by flying over a very narrow Southern Ocean from West Antarctica before its ice cap had developed and becoming, like so many others in the absence of mammalian predators, a land-dweller of the forest floor. Some flying birds, including the wrens (e.g. rifleman), thrushes (piopio) and wattlebirds (saddleback and kokako) may well have also been here since the Palaeocene.

The ratites, in New Zealand represented by the kiwi (*Apteryx* species) and the moa (*Dinornis* and other genera), lack a keel on their sternum (breastbone) to which the large wing muscles of flying birds attach; this has been used as an argument against a complete Oligocene immersion, presuming this indicates that they have been here for a very long time. This may not, however, be true and their ancestors may have even been able to fly here. The moa's closest relatives are the flighted tinamous of South America (not classified as ratites but very closely related); its ancestor might have flown to New Zealand.

below **Fossil shell found at the southern end of Poverty Bay. Gisborne District.**

Until recently it has been thought that the kiwi came from Australia, but new evidence shows that it is most closely related to Madagascar's extinct elephant bird; the ancestor of both was probably also capable of flight and long-distance dispersal and came to New Zealand later than the moa. Ratites probably evolved in South America, where the rhea is still extant, spreading throughout Gondwana not only to New Zealand (moa and kiwi) and Madagascar (elephant bird) but also to Australia (emu and cassowary), New Guinea (cassowaries) and Africa (ostrich).

LIVING FOSSILS

Several of our animals are considered to be 'living fossils'. These animals, including tuatara (*Sphenodon punctatus*) and our native frogs (*Leiopelma* species), are so-named because they evolved during Palaeozoic and Mesozoic times but were replaced elsewhere in the world by more advanced species that couldn't make it to our now separated landmass. This is an argument against a complete Oligocene immersion; frogs and earthworms, for instance, are exceedingly sensitive to saltwater and would seem to be unable to raft across the ocean to us. However, it is probable that most of our native animals arrived after the immersion and the number of ancient 'living fossils' that we have been lucky enough to inherit are few. The ancestors of New Zealand's current fauna arrived at many different times and there has been speciation, extinction and colonisation by new species throughout our history.

THE MIOCENE INVASION

When Antarctica separated from the other landmasses, it became encircled by the Southern Ocean; being isolated by a continuous, ring-like ocean with no mountainous land barrier to either current or wind allowed it to become cooler. As a result the West Wind Drift, a zone of strong westerly winds above the Southern Ocean (between 40° S and 60° S), developed. These strong winds push surface water along at speeds similar to the deeper Antarctic Circumpolar Current and have assisted many Australian and even South American plants and animals in their migration to New Zealand — not only terrestrial plants but also marine ones, such as bull kelp. Large masses of bull kelp can stay afloat for considerable distances — up to 6000 km has been reported. These floating masses not only help to propagate kelp but also provide a raft for other species such as echinoderms. Similarly, it is thought that plants such as kowhai and hebe spread throughout the Southern Hemisphere by way of their floating seeds. Even plants such as *Eucalyptus*, *Casuarina* and *Acacia* (the wattles), which we associate with Australia, became established here earlier by this means, only to be wiped out, presumably in the Pleistocene.

Animals too have been blown across by the West Wind Drift, and they are still coming — Australian moths are still blown here every year and our modern avian fauna has a very Australian aspect. In the last 100 years alone, the spur-winged plover (*Vanellus miles*),

left **'Pukeko' in Australia. Royal National Park, Sydney, New South Wales.**

black-fronted dotterel (*Elseyornis melanops*), white-faced heron (*Egretta novaehollandiae*), grey teal (*Anas gracilis*), silvereye (*Zosterops lateralis*), royal spoonbill (*Platalea regia*), Australian coot (*Fulica atra*) and welcome swallow (*Hirundo neoxena*) have self-introduced, although the red-necked avocet (*Recurvirostra novaehollandiae*) and little bittern (*Ixobrychus minutus*) have not survived. Pelicans (*Pelecanus conspiillatus*) have also recently started breeding near Dargaville, while the South Island takahe (*Porphyrio hochstetteri*) has been introduced, the northern *P. mantelli* being extinct. The takahe and pukeko (*P. porphyrio*) both derive from Australian ancestors; however, the takahe has been here longer (since perhaps the Miocene or Pliocene) and has evolved since its arrival, while the pukeko is very recent (arriving in the Holocene) and is indistinguishable from Australia's purple swamp hen. This is fortunate for the pukeko, since although the adaptations of the takahe, such as becoming big and flightless, may have been useful in the past they are a hindrance in today's changed environment. Latecomers have often found survival relatively easy compared with those species that arrived here earlier and adapted to a mammal-free environment. Indeed, some animals that have recently arrived under their own steam would not have been able to survive before such human-introduced changes. Examples of this are the swamp (Australasian) harrier *Circus approximans*, known to Maori as the kahu, and the now-common Australasian bittern (*Botaurus poiciloptilus*), both of which may have only become established here after their cousins, the Forbes' harrier (*C. teauteensis*, often considered synonymous with Eyles' harrier *C. eylesi*) and the New Zealand bittern (kaoriki, *Ixobrychus novaezelandiae*) became extinct. Prior to their extinction, the original species may have 'competitively excluded' their near relations, being better adapted to prehistoric conditions. Other self-introduced Australian species, such as the silvereye/waxeye, prefer more open habitats than the forests which previously covered the vast majority of New Zealand; the still-intact forested environment of Little Barrier Island supports significantly fewer exotic species than the mainland.

THE PLEISTOCENE

As a result of the rearrangement of the continents and subsequent changes in ocean currents, by about 2 Ma the seas were becoming very notably cooler and ever since then the Earth has been subject to recurring periods of extreme cold and ice, the Pleistocene glacial periods, brought about by minor fluctuations in the Earth's orbit, precession and wobble (Milankovitch mechanisms). Not only were these glacials cold, but they were also dry and windy. At their height, temperatures were about 5°C colder than now, the difference between the average temperature in Kaitaia (15°C) and that in Invercargill (10°C). The end of the last glacial period is commonly taken to be 10,000 years ago (10 ka), after the last very cold period in the Northern Hemisphere, although in New Zealand the ice started retreating about 14 ka. However, although in common usage 'Ice Age' refers to these glacial periods, in fact we are still in the 'Ice Ages' — just a warmer interglacial; a visit to Antarctica would confirm this.

The northern North Island was not subject to ice cover; Northland was the only part of New Zealand that kept a continuous forest cover, except on higher ground where there was grassland and conifer scrub (e.g. bog pine, *Halocarpus bidwillii* and mountain toatoa, *Phyllocladus alpinus*). This forest had a higher proportion of beech than now but there was always a significant tall-conifer component. From Auckland south only small stands of forest survived in favourable locations, such as by the coast or in some sheltered inland locations. These are known as refugia, serving as they did as refuges for plants and animals

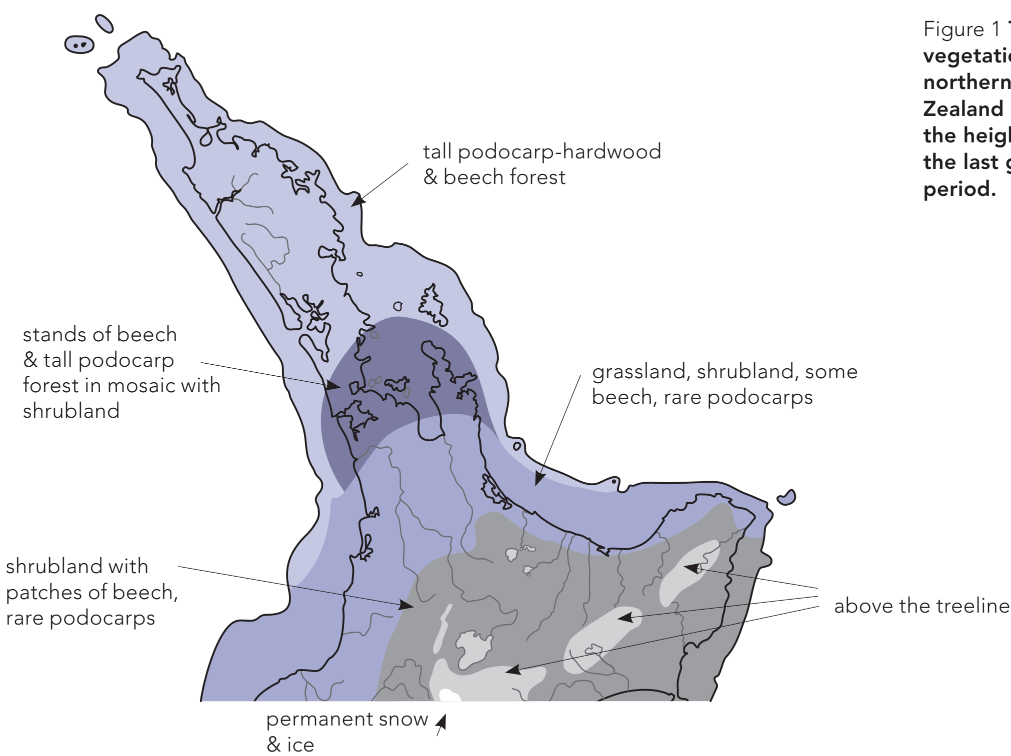


Figure 1 **The vegetation of northern New Zealand at the height of the last glacial period.**

above **A view over the Silver Peaks from between Flagstaff and Swampy summits, Dunedin City. With the exception of the pine plantation in the middle right and the yellow flowers of the gorse, such a scene might not have been out of place on the hills of northern New Zealand during the last glacial period, with forest in the lowlands but a much lowered treeline; this photo was taken at an altitude of 600 m. Note also that the cloud which formed overnight in a cool basin is now flowing over the rim of that same basin and, being colder, is descending into the valley in this early-morning photo.**

from which they could recolonise the rest of the land when conditions improved again. Most favoured would have been sheltered, north-facing slopes, where probably the most common trees were species such as silver beech (*Lophozonia menziesii*), mountain beech (*Fuscospora cliffortioides*) and mountain cedar (*Libocedrus bidwillii*); podocarp forest remnants were probably very rare, although there would have been conifer scrub species, as mentioned above. Most of the rest of the land would have been covered by shrubs, herbs, sedges and grassland or was just bare ground.

Another climatic change that occurred was that the higher parts of our west coast, such as around Waitomo, became significantly drier and this would have favoured different species.

Although northern New Zealand escaped ice cover and therefore would have provided a refuge for many of New Zealand's plants and animals, if an organism couldn't tolerate the climate here it became permanently extinct in New Zealand since it couldn't move further north, unlike in Europe or North America where species could find refuge further south. Probably particularly hard hit were the passerines or songbirds, as all those we have now would seem to have arrived since the Pleistocene. Plants of the family Casuarinaceae are also now extinct in New Zealand, even though pollens from *Casuarina* species (as well as the still-very-numerous southern beeches) are the most common angiosperm pollens from the Cenozoic. No doubt some species

were driven almost to the brink of extinction, but not quite. Therefore, every native creature that came here more than 15 ka had to be able to survive glacial periods, when the climate of Auckland was approximately the same as that of Dunedin today. Our fauna has some quite remarkable adaptations, presumably to cope with such conditions. One such is that all our geckos and all bar one of our skinks give birth to live young, whereas worldwide 60% of skinks and all other geckos lay eggs. Similarly, the tuatara's optimal body temperature, between 16°C and 21°C, is the lowest of any reptile. It can maintain normal activity down to 7°C.

THE CURRENT AGE (HOLOCENE)

About 14.5 ka, forests began spreading in the Waikato lowlands as New Zealand's climate suddenly started warming up and the glacial period, at least in this part of the world, came to a halt (it lingered on to about 10 ka in the Northern Hemisphere, with a cold snap just before the end); tree pollens (mainly of beech and native cedars, although there were a few tall podocarps) had been slowly increasing between 18 and 14.5 ka as conditions gradually improved. With the end of the Pleistocene and the melting of the majority of the Northern Hemisphere's ice sheets, sea levels rose to approximately their current position, turning landmasses such as Great Barrier into islands and filling river valleys to create our numerous harbours.

The northern North Island reacted very quickly to the post-glacial warming so that, by about 12 ka, it was almost completely forested, apart from the highest peaks. This forest had a different composition to today. Matai (*Prumnopitys taxifolia*) may well have been the most common podocarp, as opposed to today's rimu (*Dacrydium cupressinum*); and even in lowland forests, among the trees common to such forests today, there would have been subalpine trees such as mountain cedar, silver beech, mountain toatoa and bog pine. It would appear that kauri was relatively uncommon during these mild, moist conditions and podocarp-broadleaf forest was the norm, with abundant tree ferns. Totara (*Podocarpus* species) and matai are well adapted to deep, drought-prone alluvial soils with frequent frosts but, over time, they were replaced with kahikatea (*Dacrycarpus dacrydioides*), miro (*Prumnopitys ferruginea*) and rimu, with the last becoming the dominant conifer over time.

The native birds, much more numerous and diverse then than they are now, were able to transport podocarp seeds quickly. Thanks to the loss of many of those species, such as moa, and the decline of many others, that seed dispersal nowadays is much harder. Other animals important in pollination and seed dispersal, all much less common today, include lizards and invertebrates; in particular, the short-tailed bat seems to be an excellent pollinator, flitting to and fro between different plants.

Seabirds would have also been abundant, fertilising the soil near the coast with their guano, just as they are still on some predator-

free offshore islands such as the Poor Knights Islands.

As we kept warming (in fact, from around 10 to 7 ka the climate was warmer than it is now), rimu and tree ferns began to predominate in all but our driest lowland forests; and kauri, previously uncommon even in its Northland stronghold, began to become abundant throughout its current range. Subalpine trees, on the other hand, retreated to higher ground.

Climate-induced changes are ongoing. For instance, kauri could probably continue to extend its range, if current conditions persist, all the way to Dunedin, where it is more than capable of growing in today's climate. The most obvious change, though, in the last 7000 years has been the extension of beech forest. Formerly it was relatively scarce in the north — perhaps with scattered trees in our axial ranges and our southwest, and possibly present as forest on inland ranges east of Tongariro. Since then, beech has extended significantly, with the higher parts of our axial ranges now predominantly beech, and it is expanding into the higher ground of our forested southwestern border (near Taranaki) and on the Kaimai and Mamaku ranges. Hard beech was very common even on Auckland's North Shore, along with kauri, before humans destroyed it — which is why many would not think of the North Shore as being a beech stronghold.

Since the Pleistocene came to an end, there have been other natural upheavals. The central North Island was massively affected by the huge Taupo Volcanic Zone (TVZ) eruptions. The aftermath of these events are still all around us; for instance, while Northland has a high diversity of earthworms, there is a much-reduced diversity in the central volcanic lands which probably has something to do with repeated smothering of the ground surface with large volumes of hot volcanic ash, as much as Northland being an older country and a better Pleistocene refuge. Nevertheless, just as nature recovered very quickly at the end of the Pleistocene, so too it reclothed the countryside after those eruptions within a very short space of time.

NORTHERN NEW ZEALAND IMMEDIATELY PRIOR TO HUMAN SETTLEMENT

It must be remembered that, prior to human settlement, we had a much more diverse fauna. Many native animals are now extinct, and others still extant are either scarce or confined to island sanctuaries and cannot play a significant role in the mainland ecosystem; yet clearly both the extinct and the rare must once have had important ecological roles. Our ecosystem has evolved and functions as if they were still present, but instead we have 40 or so introduced mammalian species, 30 or so introduced birds and innumerable and increasing numbers of introduced invertebrates and plants. Such ecological roles would have included pollination, grazing and predation as well as being food for larger organisms, and clearly this would have resulted in a very different ecosystem, both plant and animal, than what we have now. For instance, beech mistletoes are not only grazed by introduced possums but also rely on a small number of native birds and insects (such as tui and some native bees) for pollination; if the pollinators go, then so too does the mistletoe.

As a result, before humans arrived our whole landscape must have been vastly different to what it is now. It would have been almost completely covered in forest, excepting lakes and freshwater wetlands (the latter being particularly common in the Waikato basins), a few isolated high summits and around the coast.

ANIMALS ADAPTED TO THEIR ENVIRONMENT

In the absence of small mammals, various other animals occupied niches that, in other parts of the world, mammals would occupy. Some particularly notable absences were predators that hunt at night using smell rather than sight, large grazing herbivores and the whole range of small mammals that inhabit the forest floor, digging the leaf litter for food (which consists, in the main, of invertebrates).

Hence the aforementioned takahe, which became flightless and larger (gigantism) as it adopted a mammal-like grazing habit, both because of the absence of efficient mammalian predators and because of the availability of that ecological niche. Flightlessness and gigantism are common themes in not only our birds but also many other species — for instance, the now rare giant weta (*Deinacrida* species). As a result, moa and other large herbivorous birds became our equivalent of the weighty mammalian grazers elsewhere (e.g. cows), while down on the forest floor giant weta were widespread, filling the ecological role that mice do now. Other forest-floor inhabitants included tuatara, which one could consider as occupying the ecological niche of a rat, snipes (*Coenocorypha* species) and short-tailed bats; but perhaps the most superbly evolved of all for this habitat is our national bird, the kiwi. The kiwi is a very mammalian bird — a nocturnal forager reliant on a sense of smell, and having a special sense organ for vibration. It is also equipped with whiskers and one of the largest brains for its body size of all birds. In most other countries, mammals such as moles predominate on the forest floor.

Large, flightless species such as the kakapo (*Strigops habroptilus*), our extinct goose (*Cnemiornis gracilis*) and moa have been particularly hard hit by the introduction of mammalian predators because they had evolved in a world without them. At the time, however, these adaptations made sense. Gigantism is a useful adaptation for herbivores, as large animals require less intake of energy (food) per unit of weight than small ones, especially if their diet is a fibrous, low-energy one. Even smaller birds, such as Finch's duck (*Chenonetta finschi*) became larger than other ducks as well as flightless. Another mammalian innovation that many native New Zealanders made was to have smaller clutches of eggs with more-developed offspring — which has turned out not to be so wise, but is common in species that live relatively free from predation and in stable environments. This so-called K-selection reproductive strategy — investing a lot in the survival of each offspring but having smaller numbers of them — is good if a decent proportion of the young survive; it is generally adopted in species that are usually near the carrying capacity, i.e. the maximum number of that species that can be supported by the area in question. However, if mortality is high among one's young an r-selection strategy, entailing having lots of young and investing little in each but hoping a few survive, is generally more beneficial to the survival of the species. Some natives, such as saddlebacks (*Philesturnus carunculatus*), can change to having large clutches if conditions are favourable, although many cannot. Of course, those introduced animals with an r-selection strategy that end up facing few natural predators in their new home do particularly well, such as many introduced animals that have ended up on our shores.

Although there were no mammalian predators, bar three species of (predominantly insectivorous) bat and marine mammals hauling themselves inshore, there were certainly predators — the largest being the birds. Today we have three avian predators, all closely related to similar species in Australia:

the Australasian harrier, the New Zealand falcon (*Falco novaeseelandiae*) and our native nocturnal predator, the morepork (*Ninox novaeseelandiae*). However, before humans came we also had goshawks of a size that could take out pigeons, kaka and takahe, and probably also a huge sea eagle (*Haliaeetus australis*) that was certainly present on the Chatham Islands, although none of these could tackle the larger birds. Nationally, the biggest predator of all was the giant Haast's eagle (*Harpagornis moorei*), the largest and most powerful eagle ever to exist anywhere in the world with a lifespan of perhaps 20 years, although there is no evidence of its presence in the North Island. Instead, the North Island's largest avian predator was Forbes' harrier, a type of hawk adapted to life in the closer environments of forest and scrub; it hunted other birds and was twice the size of the extant swamp harrier.

Since most predation pressure came from birds, which rely on sight to hunt and in general are more active during the day, the adaptations of being nocturnal, freezing in place and relying on camouflage were undoubtedly useful and are common in our native animals. However, these strategies are often doomed to failure when prey are pursued by a mammalian nose or caught in car lights; running or flying would probably be much more useful.

There were, however, three nocturnal avian predators. These include the still-extant nocturnal morepork and the extinct laughing owl (*Sceloglaux albifacies*) and owlet-nightjar (*Megaegotheles novaezealandiae*), none of which could tackle the larger birds such as moa. The morepork is mainly insectivorous, although it can take birds up to the size of a saddleback; the laughing owl was bigger, and capable of predating the morepork. Its diet probably ranged from large insects up to weka, bats and tuatara and it survived in Polynesian times, partly on a diet of rats! The owlet-nightjar was probably a poor flier and, as well as insects, ate small vertebrates such as lizards and frogs, once common on the forest floor.

INHABITANTS OF THE FOREST

The forest that covered our land at that time would have resounded with birdsong, of which only faint echoes survive in the dawn chorus of sanctuaries such as Tiritiri Matangi Island. Instead of deer and pigs, our forests would have been browsed by large flightless birds, both extinct (e.g. moa and the adzebill) and extant but rare (e.g. takahe); this may have given rise to a very different grazing pressure to that we have now and may have driven the evolution of our plants, possibly (though it is debatable) giving rise to the characteristically New Zealand divaricating shrub. These browsers would have also been important in the transport of large seeds (such as those of

below **North Island takahe skeleton, Waitomo Museum, Waitomo District. Image reproduced courtesy of the Waitomo Museum of Caves.**

tawa), especially in the revegetating of our landscape after volcanic eruptions and, as we have already seen, glacial periods.

There were perhaps nine species of moa, although only four lived in northern New Zealand (and the North Island as a whole); the greatest variety lived in the drier eastern part of the South Island. Moa were also found on our larger offshore islands, including Great Barrier Island, and were herbivorous. Unusually among similar birds, such as emus, the ranges of different species often overlapped. The most widespread was also the smallest, the forest-dwelling little bush moa (*Anomalopteryx didiformis*), being 50 cm tall and weighing around 1.5 kg, about the size of a goose. The largest of all moa were the giant moa, the North Island giant moa (*Dinornis novaezealandiae*) being slightly smaller than the South Island giant moa (*D. robustus*) which could weigh up to 200–300 kg and was 1.6 m high at the hip. The giant moa inhabited all habitats, being a generalist, and was quite probably semi-nomadic (depending on the season), as probably were all moa to some degree. Other moa found in more-open environments in northern New Zealand included the widespread stout-legged moa (*Euryapteryx curtus*), about 1 m tall and weighing up to 100 kg — the female being much larger than the male — found particularly in places near the coast or on land cleared by volcanic activity. Mantell's moa (*Pachyornis geranoides*) tended to live on forest edges and in swamps and was the most common moa on the East Coast. All had long life and light predation pressure; thus, like many other long-lived birds, they had few offspring. Some moa may have lived as long as 80 years; we have evidence of osteoarthritis in moa bones, testimony to such a span of years.

A most peculiar bird was the North Island adzebill (*Aptornis otidiformis*), never as common as moa, which lived in the drier and more open east coast forests and weighed up to 10 kg. A type of rail, slightly smaller than the South Island one (which is common in many

below **Before the coming of humans, northern forests were home to creatures such as, from left to right, the Northland skink, Eyles' (Forbes') harrier, laughing owl, piopio (New Zealand thrush), huia, and bush wren. All are now extinct. Illustration by Dave Gunson, from *Lost Worlds of Aotearoa* (Random House).**

species, perhaps due to the warmer climate), it probably probed the soil or rotten logs for insects, tuatara and seabirds nesting in their burrows. The stout-legged wren (the largest of our wrens; the slightly smaller North Island species is called *Pachyplicas jagmi* and was either flightless or nearly so) also made a living on the forest floor, alongside the still-extant but declining kiwi and the very rare and flightless kakapo. Similarly filling more mammalian-type niches was the previously mentioned Finch's duck: flightless, heavy and possibly once our most common duck. The stout-legged wren and Finch's duck are gone. The small snipe-rail (*Capellirallus karamu*), found initially in Karamu Cave near Waitomo and in general in the wetter western North Island, was also such a creature; it probably probed soft soils, mosses and deep litter of the wet podocarp forests for its food. Ironically, one of our very few land mammals, the short-tailed bat, also adopted a ground-based foraging lifestyle from which its ancestors had fled.

Living on the forest floor and still extant, although in much more limited numbers than before, were two other rails, the takahe and the weka. As previously mentioned, the North Island takahe or moho has become extinct and it is its smaller South Island relative *P. hochstetteri* that has been introduced to some of our offshore islands such as Tiritiri Matangi. The weka (*Gallirallus australis*) is a derivative of the banded rail, common throughout much of the Pacific. Other now-extinct rails included Hodgens' water hen (*Gallinula hodgenorum*), a widespread but flightless small rail, possibly a forest-dweller as well as living by lakes; and the (probably flighted) New Zealand coot (*Fulica prisca*), which may have been relatively terrestrial unlike others of the same genus, although probably preferred more-open country such as by the coast and lakes and has also been found in the Waitomo Caves. The current coot visible in New Zealand is the common coot (*F. atra*), which became established here in 1958.

In the forest canopy, alongside familiar native birds still common today such as tui (*Prosthemadera novaeseelandiae*) and fantails (*Rhipidura fuliginosa*), one would have also found huia (*Heteralocha acutirostris*), which may have always been confined to the North Island, and the native raven (*Corvus moriorum*), which fed on fruit, large insects and carrion like its extant relatives overseas; the other wattlebirds, the North Island kokako (*Callaeas cinerea wilsoni*) and North Island saddleback (*Philesturnus carunculatus rufusater*), would also have been much more common than they are now. Another living fossil with deep ancestry in New Zealand but now gone was the native North Island thrush or North Island piopio (*Turnagra tanagra*); also a poor flier, it favoured forest undergrowth. There was also a (flighted) North Island snipe (*Coenocrypha barrierensis*), probably an insectivore, about which little is known.

SEABIRDS

Seabirds would also have featured much more prominently around our mainland coastline, rather than the majority being confined to offshore islands and hard-to-reach cliffs as they are now, again because of predation on land where they breed (although they are also killed at sea, for instance by poor fishing methods). At dusk the sky above the coast must have been thick with arriving birds and their guano would have provided important fertiliser and, as still happens on offshore islands, their burrows would have also been shared with other animals such as the tuatara.

ANIMALS OF OPEN ENVIRONMENTS AND WATER

The final rail, which survived into European times, preferred to forage in more-open

environments such as grassland, by the coast and shrubland and hence was more common in the eastern South Island. This was the New Zealand quail (*Coturnix novaeselandiae*) which probably met its demise at the hands of Norway rats (*Rattus norvegicus*) and cats (*Felis catus*). The quail one usually sees now is the California quail (*Callipepla californica*) from western North America, although Tiritiri Matangi Island has a population of Australian brown quail (*Coturnix ypsilophora*).

Also in more-open environments, such as swamps and beside stream banks, lived a similar large herbivore — the 10-kg North Island goose (*Cnemiornis gracilis*), slightly smaller than its South Island cousin. It probably grazed on grasses and sedges. Further out, on open freshwater, one may have been able to spot the native swan (*Cygnus sumnerensis*) and pelican (*Pelecanus novaezealandiae*); down by the coast, not only seabirds but also sea mammals would have been much more common, such as the New Zealand fur seal which was almost extirpated from our shores, first by Maori and then by Europeans and starting in the north, although they are slowly making a comeback since becoming protected. There may also have been a distinct species of prehistoric sea lion, which was exterminated by Maori. The southern merganser (*Mergus australis*) dived and caught fish on inland waterways as well as at sea, accompanied by the New Zealand musk duck (*Biziura delautouri*) and New Zealand stiff-tailed duck (*Oxyura vantetsi*) on large areas of permanent water as well as the shallow-water-feeding Scarlett's duck (*Malacorhynchus scarletti*); all were probably victims of Maori hunting. Also in wetlands such as swamps and on creek banks and lagoon edges was to be found the New Zealand bittern, which survived into European times.

In the water there were also more fish than we have now, including the New Zealand grayling (upokororo, *Prototroctes oxyrhynchus*), a galaxiid that was bigger than today's giant kokopu; it went extinct in the 1920s. Also, just like on land, because of introduced species and such problems as eutrophication, those species that are still extant used to be more widespread and common.

THE ARRIVAL OF HUMANS

The arrival of humanity, starting with Maori around AD1300 and continuing with Europeans in the 18th century (barring one visit by Abel Tasman in the 17th century), has truly been an unmitigated disaster for the vast majority of the living organisms native to these shores; 40% of forest and freshwater birds have become extinct since humans arrived, despite many having survived Ice Ages, volcanic eruptions and Oligocene immersions. We have also lost reptiles, three species of native frog, and almost certainly innumerable invertebrates that we have no idea even existed! Indeed, our supposedly clean and green country probably holds a record for animal extinctions.

The basic cause of extinction has been environmental modification in a manner that has not suited those plants and animals that had already adapted to New Zealand's pre-human environment; examples being the clearing of forest to make way for farmland

and predators that hunt in a different manner to that native species are used to.

Such changes affected different animals in different ways, and often several pressures contributed to a species' demise. Some animals, such as moa, were actively hunted by humans; some were hunted by the pests they brought with them, such as the mustelids that continue to destroy our avifauna; and others were exterminated by loss of habitat due to land clearance and drainage of wetlands. Some were caught up as collateral damage, with some predator species going extinct when their prey went extinct. Coastal animals were not immune, either. Before the arrival of humans, seals probably inhabited all of our shores but were almost all eliminated from northern New Zealand by Maori — to survive in more-southern locales until the arrival of European sealing gangs. Following legal protection from 1916, fur seals have slowly been making a comeback; particularly in the south, but they are also more visible in northern New Zealand than previously, although nationwide their numbers are probably only 10–20% of what they once were.

While plants were deliberately cleared, the systemic destruction of the fauna and its replacement with an introduced fauna, such as deer and rats, continues to place selection pressures on our plant ecosystems, with resultant loss of species diversity. Perhaps the most obvious recent example in northern New Zealand is the decline of the pohutukawa and rata (*Metrosideros* species) caused by possums, which love to eat tender new shoots which eventually causes the death of such plants.

LAND CLEARANCE

Both Maori and Europeans cleared large tracts of land. Coastal areas, lowlands suitable for agriculture and forests producing desirable timbers were particular targets; many of our upland areas, more remote and less fertile, have been relatively spared. Hence the appearance of much of our countryside as lowland pasture with bush on the hills. The eastern forests away from the axial ranges suffered a worse fate; being dry, the forests here were destroyed by fire, never to return, which led to our current erosion problems.

Many of our lowland areas were originally burnt by Maori; for instance, the lowlands of the Hamilton Basin and the Tamaki Isthmus on which Auckland city is built were, by the time of the arrival of Europeans, covered by bracken, a rapid coloniser of cleared ground. Maori fires may also have been responsible for the conversion of forest into gumlands in Northland, where forest has been unable to re-establish itself. Northern New Zealand was the part of the country most densely inhabited by Maori, as it is now, and was therefore heavily affected. Europeans continued in the same vein, clearing land for agriculture and harvesting forests for lumber; lowland and valuable timber trees such as kauri and kahikatea were widely decimated. Wetlands such as those of the Hauraki Plains, those in the Waikato lowlands and around Kaitaia, and many others, were drained to provide fertile pasture; it is said that 90% of wetlands in New Zealand have been drained, although perhaps this percentage falls to 70% in the Waikato. Urban development has also continued apace, once again more intensively in the north than elsewhere in New Zealand because of its population, half of all New Zealand's.

Despite being less-attractive farming country, much of the bush on our hill country is also secondary, following the extraction of forest giants and associated fires in places such as the Coromandel Peninsula. This has resulted in a patchwork land with greater survival of some ecosystems (such as tawa and beech forest) than others (such as kauri and kahikatea forest), and a massive loss of our

above **Remnant lowland bush on the Gisborne Plains, dominated by kahikatea. Once bush like this would have covered the majority of our alluvial plains and basins. Gray's Bush Scientific Reserve, Gisborne District.**

predominantly lowland wetlands.

The native fauna has, for the most part, suffered in a similar fashion due to the loss of its familiar habitat, although there are notable exceptions — such as grass grub, Australasian harriers and the porina moth — that have found themselves in a better environment than they had before.

INTRODUCED ANIMALS

Introduced pests reduce native animal numbers most commonly by predation; for instance, stoats are well known as killers of young kiwi although adult kiwi are better at defending themselves. They may also compete with native animals for food and destroy native habitat; possums consume tons of native plant material every night and, as mentioned, have decimated rata and pohutukawa throughout the country. Fortunately, some offshore islands have remained either completely or relatively pest-free and have acted as refuges for those native species unable to compete with the introduced fauna on the mainland. More islands have been made pest-free by the use of poisons, and areas of the mainland are now also being fenced off or regularly poisoned to try to help native wildlife become re-established on the mainland. Northern New Zealand is particularly important in this regard because of the large number of such

islands. It also contains many important mainland sanctuary projects, ironically because of its larger human population — finally we might be doing our bit!

INTRODUCED MAMMALS

Presumably the first Polynesian people to arrive brought with them the kiore (Polynesian or Pacific rat, *Rattus exulans*) and kuri (Polynesian dog, *Canis lupus familiaris*); the kiore may have arrived here around AD1, before the main colonisation of New Zealand by Maori in approximately AD1300. The kiore in particular had previously exterminated many animals on more-tropical Pacific islands and may have been brought to New Zealand as a food source. As already alluded to, mammalian predators have an extra advantage that native animals have not adapted to cope with — they can smell. Freezing, being nocturnal, and using camouflage to fool predators may work very well if you are being hunted by a bird dependent on sharp vision, such as a hawk or an eagle, but not if a nocturnal mammal can smell you out. Moreover, if you can't fly away or if you lay your eggs on the ground where they can easily be eaten, you are in double trouble. The only climbing predators that could feed on eggs prior to human arrival were tuatara and some species of gecko and skink. Dogs (though no longer kuri) continue to damage our precious wildlife; in 1987 perhaps 400–500 kiwi were killed by the actions of one lone dog in the Waitangi Forest. In one study, dogs were found to be responsible for 78% of Northland kiwi deaths by predation.

When Europeans arrived, the situation only deteriorated. More animal species continue to arrive even now. Many species of animal have been introduced to New Zealand, from economically vital sheep and cattle to pest animals of no economic value such as stoats (*Mustela erminea*), ferrets (*M. putorius furo*) and yet more rats. Some of these pests were even introduced to try to control other introduced pests; mustelids fall into this category, brought in to combat the plague of European rabbits (*Oryctolagus cuniculus*). Others, such as the Norway rat and ship rat (*Rattus rattus*), have hitch-hiked their way here, stowing away on ships; these two are such efficient predators that they have driven the kiore to extinction on the North Island, although two islands (Mauitaha and Araara) have been set aside as a kiore sanctuary in the Hen and Chickens group. Competition with mice may also have been a factor in the mainland extinction of kiore, as the spread of mice seems to correspond with the decline of the latter. Pest species continue to arrive despite our border biosecurity, although without that the situation would be even more dire.

Rats are prolific breeders; the ship rat is arboreal and an excellent climber, decimating many bird populations; their main predator is the stoat, another introduction and a proficient hunter of our avian fauna. Fortunately, no stoat has managed to reach Little Barrier or Great Barrier islands. Weasels and ferrets are other, less-widespread introduced mustelids; mustelids inhabit not only bush but everywhere up to the alpine vegetation limit and are almost entirely carnivorous, eating almost anything — birds, mice, rats, insects and even rabbits and hares.

We also have bigger pest mammals, although some value them for hunting. In Te Urewera the most aggressive coloniser has been the red deer (*Cervus elaphus scoticus*), which along with the possum has wrought untold damage to native trees; its browsing and foraging not only reduce existing plants but also inhibit regrowth. Red deer are also present in the forests of the Raukumara Range as well as on the forested ranges west of Lakes Taupo and Rotorua (Pureora and

Kaimai Mamaku forest parks). Other species of deer (sika or Japanese deer, sambar and Javan rusa; the latter only near Galatea in the eastern Bay of Plenty) are also present in parts of the north, and pigs, wild cattle and goats from adjoining farmland maraud through our forests. Wild pigs (*Sus scrofa*), crossbreeds between those that Captain Cook released in 1773 and feral pigs of many varieties, are common predominantly in the bush-covered hilly areas of the mainland North Island, such as the Coromandel, Hunua and Waitakere ranges and the Northland ranges, as well as in the Central Plateau and axial ranges. They are omnivores — eating carcasses, berries and roots — and often roam in family mobs; a pig invasion can turn bush or pasture into a 'ploughed' field! Such pigs may have been the reason Maori had to abandon gardens in valleys such as that of the Motu River. Goats are a potential suspect in skewing native forest regeneration in the Hunua Ranges towards conifers as opposed to the broader-leaved hardwoods.

Less offensive perhaps is the tammar wallaby (*Macropus eugenii*), which lives in the exotic forests around Rotorua and on Kawau Island. Indeed, this introduction was fortunate in that the subspecies introduced to New Zealand (*M. eugenii eugenii*) had become extinct in its former South Australian homeland and was subsequently reintroduced from New Zealand.

Hedgehogs (*Erinaceus europaeus*) are night hunters of insects, worms and other invertebrates as well as lizards and are now more common in New Zealand than in Europe, thanks to a relative absence of predators. They hibernate in winter, for only a few weeks in Northland but for longer further south. In the Scottish Hebrides, where they have only recently been introduced (1974), hedgehogs would appear to be decimating populations of ground-nesting wading birds and no doubt the same is happening in New Zealand.

Brushtail possums (*Trichosurus vulpecula*), liberated between 1837 and 1875 for food, fibre and its pelt, including in Auckland, are now found throughout the northern North Island. They feed primarily on leaves with some fruits and flowers and are particularly found in forest margins and remnant forest surrounded by grassland, where they obtain food from both the forest and the grassland. Our pohutukawa and rata trees have been particularly unfortunate subjects of their attention, and 'Project Crimson' has been set up to try to help these trees. Possums also eat the tender tips of young trees in pine plantations, predate bird eggs (being omnivores) and are a vector for bovine tuberculosis into the bargain, adversely affecting our agriculture.

INTRODUCED INSECTS

Many insects (on which there is more detail in Chapter 7) have also been introduced and can be highly annoying to humans and dangerous to our native wildlife; examples include the Asian paper wasp (*Polistes chinensis*) and multiple species of ant. Other insects are economically vital, such as the introduced bumblebee (*Bombus* species) and honey bee (*Apis mellifera*), both of which are more noticeable than our native ants as they are larger and live in colonies.

One of the most unloved pest insects must surely be the cockroach; there are several native forest species but it is the three invaders, the German (*Blattella germanica*), American (*Periplaneta americana*) and Australian (*P. ausralasiae*) cockroaches, that enter our houses for warmth (enabling better breeding) and food. The Gisborne cockroach (*Drymaplaneta semivitta*) was introduced from Australia, being first found in Gisborne (hence the name) — it has now spread throughout the North Island and has been

found in Nelson, Blenheim and Timaru in the South Island.

There are also self-introduced species such as the monarch butterfly (*Danaus plexippus*) from North America, which feeds on milkweeds (family Asclepiadoideae) that people often plant; they are poisonous to most other species. Before these plants were introduced to New Zealand the monarch couldn't survive even if it had ventured to our shores, as it surely did.

OTHER INTRODUCED ANIMALS

Almost every other major group of animal has also been introduced, including vertebrates such as frogs, lizards (e.g. the rainbow skink, *Lampropholis delicata*), birds (e.g. the common myna, *Acridotheres tristis*) and freshwater fish (e.g. carp species) as well as invertebrates. Most thrive, adapted as they are to current conditions, often outcompeting native species for food and habitat.

EXTINCTIONS

Hand in hand with introduced animals and land clearance go extinctions and, as already mentioned, we have lost 40% of the pre-Polynesian bird species since humans arrived here, mostly in pre-European times. However, Pakeha cannot place all the blame on Maori. Since European settlement, extermination of the native landscape, fauna and flora has increased in pace and many of those species still holding on after the Maori onslaught were exterminated by additional Pakeha pressures; some that still survive do so only on offshore islands.

AVIAN EXTINCTIONS

The most obvious group of extinctions, given the size of animals involved, was birds. Vast numbers of moa bones have been found in Maori middens, with particular hunting sites being the Coromandel and Aupouri peninsulas; the Gisborne District is also a particularly rich site for subfossil moa. Quite possibly, having not evolved alongside such hunters, they did not even realise that the human or kuri had food on the mind when creeping up on them! Local extinction of moa may have taken only 10 years on the Coromandel Peninsula. Their eggs, being both large and laid on the ground, would also have been a feast for early Maori, and for introduced animals such as the kiore. All species of moa were finally exterminated about 400–500 years ago, although perhaps some smaller ones held on longer.

Other large flightless birds, such as the adzebill and native goose, were probably also slow and fat and similarly easy prey; South Island takahe only just managed to hang on in one valley of the isolated Murchison Mountains in Fiordland although it has subsequently been re-introduced to a select few sanctuaries elsewhere, including Auckland's Tiritiri Matangi Island (although the North Island takahe is extinct). The smaller flightless birds of the forest floor haven't fared much better — the various species of kiwi are all endangered to varying degrees, their eggs and young eaten by rats and mustelids and their adults targeted by feral dogs, and weka are gone from most of northern New Zealand (although some survive in the wild around Kawakawa Bay, eastern Auckland); while the stout-legged wren, Finch's duck and the small snipe-rail are all gone.

The large, flightless and meaty birds such as moa, geese and adzebills were probably all gone very early, around AD1400, due to predation by humans and kiore. Some smaller flightless birds such as Finch's duck and the stout-legged wren were also gone by the time Captain Cook arrived in 1769. Many that did survive Polynesian settlement hung

on into European times only in remote or island locations where they could escape the full attentions of kiore and/or Maori; and Europeans and their predators then just finished off the last few.

However, some birds survived both Maori and kiore reasonably well and were reasonably numerous in early European times; the North Island piopio's demise was probably caused by ship rats, while European rats, cats and mustelids probably exterminated the laughing owl. Some rails probably also fall into this category, such as the New Zealand quail (its fall due to cats and Norwegian rats), as do endangered ones such as weka.

Some of the flighted birds, especially the weak fliers and those less careful with their eggs, have also vanished, thanks to predation by introduced mammals as well as human hunting. Several smaller birds were probably in the main hunted to death by Polynesian settlers, including the New Zealand musk duck and New Zealand coot, both probably poor fliers, and the stiff-tailed duck which, although it probably flew well, was likely to have been relatively helpless on land. The huia, native raven and native North Island thrush or North Island piopio are also all gone; the last raven probably went into a Cantabrian's cooking pot around 1850 and its ground-nesting habit would have provided an easily accessible source of eggs for rats. The huia, a wattlebird with a long history in New Zealand, survived in the lower North Island until the early 20th century, when the last was shot so that it could go on display in a museum! Other wattlebirds, including the North Island saddleback and kokako, are only just hanging on; the South Island kokako (*Callaeas cinerea cinerea*) is almost certainly gone.

The small insectivorous New Zealand snipes were once also distributed throughout not only New Zealand but also up to Fiji, Norfolk Island and New Caledonia; the North Island snipe (also known as the Little Barrier snipe) used to be present throughout the North Island but is now extinct (it survived on Little Barrier Island until cats arrived there in the 1870s, despite the presence of kiore, although the latter may themselves have reached Little Barrier only just before, rather than early in Polynesian settlement). Likewise extinct is the small snipe-rail; the only remaining snipe species are on outlying islands in the Chathams and subantarctic islands. Promisingly for these species, those Campbell Island snipes (*Coenocorypha aucklandica perseverance*) that survived on tiny Jacquemart Island off the main island are now making a comeback on Campbell Island itself, after rats, a snipe's main enemy, were eliminated from that subantarctic island.

Four species of New Zealand's six tiny insectivorous wrens (Acanthisittidae), including Lyall's wren (*Xenicus lyalli*; previously *Traversia lyalli*), the smallest flightless bird in the world, have been exterminated from New Zealand since human settlement; the last Lyall's wren collected was caught by a cat in 1895 on Stephens Island in Cook Strait. Kiore had probably polished off those on the mainland centuries earlier, given their increasingly flightless nature, although once they would have been very common — even the so-called South Island wren was present in the North Island, with only the rare long-billed wren (*Dendroscansor decurvirostris*) missing from northern New Zealand. Wrens were the most diverse family of songbirds in New Zealand and the most ancient in lineage; they are probably one of our original Gondwana families. However, in the north we are now left with only the rifleman (titipounamu, *Acanthisitta chloris*), which has nevertheless succeeded in entering some exotic pine plantations, especially those of *Pinus radiata* (Monterey pine), although it is predominantly found in lowland tawa

forest south of Te Aroha.

Forest birds were perhaps the most obviously hit of the avian species, but we would also have provided a predator-free paradise for nesting seabirds, such as the New Zealand storm petrel (*Fregatta maorianus*, rediscovered in 2003). It is no accident that its only known breeding site is the now completely predator-free sanctuary of Little Barrier Island.

Also gone are the open-water native swan and pelican. Both have close Australian relatives, and recently Australian pelicans (*Pelecanus conspicillatus*) have been spotted trying to recolonise the waterways near Dargaville.

We have also lost several of our avian predators, including Forbes' harrier, our largest, which went extinct due to a combination of pressures, including:

- it had become too well adapted to forest and shrubland, having a flapping flight supporting a heavy body, to readjust to life in more-open country once Maori arrived
- it probably preyed on small moa as well as other birds and hence lost some of its prey when they went extinct
- it appears to have been palatable to humans and most likely its eggs and chicks were vulnerable to rats.

The nocturnal owlet-nightjar (which, if it could fly, could only do so very poorly) and laughing owl are also gone; similar pressures, such as loss of prey and habitat as well as predation, were the cause of their extinctions.

OTHER ANIMAL AND PLANT EXTINCTIONS

Not only birds have become extinct, although as mentioned they are the easiest to identify because of their size; we really have no idea how many small invertebrates have gone, but no doubt the number is large.

Of the reptiles, we used to have the largest gecko ever, the giant gecko kawekaweau (*Hoplodactylus delcourti*), which was as thick as a man's arm according to Maori. It also was a forest-dweller and probably delighted

left **The greater short-tailed bat. Crown Copyright Department of Conservation: Te Papa Atawhai, 2005.**

in basking on the limbs of forest trees; it just survived into early European times (around 1870). We have also lost some native frog species and, undoubtedly, various geckos and skinks. We are of course lucky to still have the tuatara and some native amphibians, skinks and geckos; but many of them, including tuatara, have been reduced in numbers and only hold on in sanctuaries from where, in due course if there is no human intervention, they will probably also become extinct. We have lost species even in recent times despite attempts at intervention; one of the most recent is one of our few mammals, the greater short-tailed bat (*Mystacina robusta*). Its last main refuge on Big South Cape Island near Stewart Island was scoured by a rat plague and the last member of the species was caught on nearby Solander Island in Foveaux Strait in 1967.

Many native invertebrates have also become extinct while others have become confined to small remnant populations, often on predator-free islands. Like some of our native birds, some evolved to become large, ground-dwelling and flightless (for instance the giant weta, the tusked weta and giant weevils); just as with birds, in many cases this has further imperilled their survival. Often their main defence mechanism is to stand still, a useful defence against native predators such as birds but not against mammals that hunt by smell as well as by sight, such as rats, mice, hedgehogs and possums. Other invertebrate groups to feature prominently in the extinction list include land snails and beetles.

It is not only animals, however, that are endangered by introduced animals; herbivores and omnivores are also enemies of plants. For instance, the shrub turepo (long-leaved milk tree, *Paratrophis* or *Streblus banksii*) is hard to find on the mainland but is much more common on rat-free islands in the Hauraki Gulf and the islands east of the Coromandel. There is hope, however, for what we have left; perhaps our biggest weapons in avoiding further extinctions are predator-free islands and mainland sanctuaries coupled with modern scientific miracles such as 1080, cyanide and brodifacoum, as well as the will and the drive of the whole community. 1080 in particular is highly mammal-specific; for instance, lizards could not eat enough to get a lethal dose of 1080 even if their diet consisted entirely of animals poisoned with it! Unfortunately, there is opposition to some of these agents not for any real scientific reason but because of misinformation spread by various either uninformed or vested interests. Cyanide's main target is usually the possum (and another marsupial, the tammar wallaby), while brodifacoum is probably best known as a rodenticide. Although some native animals may be killed during pest-control operations, the benefits which such operations bring by controlling or eliminating predators and competitors far outweigh the costs.

EXOTIC PLANTS

Many plant species have been introduced to New Zealand — deliberately, accidentally or even illegally. The first came with our earliest settlers, the Maori, although these plants, including taro (*Colocasia antiquorum*) and kumara (*Ipomoea batatas*), being of tropical provenance and difficult to propagate even in our northern climates (kumara, for instance, cannot overwinter in Auckland), never made as big an impact as kiore. New arrivals continue to this day. Northern New Zealand has the two busiest cargo ports in the North Island — Auckland and Mt Maunganui — as well as the country's busiest international airport, ensuring that it continues to remain the most common

first stop for new arrivals; the slightly warmer climate also means a greater range of species is able to survive than further south. The disturbance of the native flora by human activities allows introduced species to gain a foothold, and plants in particular may be further distributed by being carried around on machinery such as tractors and in garden waste. Once introduced species become self-sustaining in the wild they are termed naturalised; New Zealand has about 2000 naturalised plant species (about the same number as native species), but many of the more than 20,000 introduced species, often planted as ornamentals in people's gardens, are becoming naturalised. In Auckland, one new species becomes naturalised every 3 months. Even trampers can cause devastation; some trails in the Waitakere kauri forests near Auckland have been closed because trampers (and their dogs) are spreading kauri dieback (caused by a microscopic fungus-like pathogen, *Phytophthora* 'taxon Agathis' or PTA).

Small species have changed the look of much of our landscape. Kikuyu grass (*Pennisetum clandestinum*), a hardy African grass that stays much greener in dry summers than do native species, is very common in northern New Zealand, taking over from native grasses in pastures and natural grasslands; in sand dunes, another non-native, the European marram (*Ammophila arenaria*), often replaces pingao (*Ficinia spiralis*) and spinifex (*Spinifex sericeus*) as the sand binder of the foredunes. Many have more colourful flowers than the natives and were originally introduced as ornamental garden plants, such as montbretia (a hybrid *Crocosmia* x *crocosmiiflora*), first found in the wild near Thames in 1929 and now everywhere. Climbers such as blue morning glory (*Ipomoea indica*) smother native trees and shrubs; some can grow at a rate of 15 cm per day and are very difficult to eradicate, particularly as doing so may endanger the plants supporting it. Wandering Jew (*Tradescantia fluminensis*) is a creeper that roots at intervals and is easily breakable, making it difficult to just pull out as each individual piece left behind takes root.

Some introduced species may potentially be helpful, in the right circumstances. Gorse (*Ulex europaeus*) can be a pioneer in places that native plants find difficult to colonise; it is a nitrogen-fixer, allowing it to survive in nitrogen-poor soils. If left alone, it will provide a sheltering canopy and more nutrient-rich soil that can then allow natives such as manuka to establish and eventually grow over the top of it. Very dense gorse thickets will exclude natives, but after about 20–25 years these stands will thin out as the older plants die and then native trees may be able to become established.

Some species may not seem particularly foreign, but could be considered as such. A kauri tree planted in Gisborne could certainly be considered so, as kauri, despite being native to New Zealand, are not native to Gisborne. To a purist, even planting certain kauri in Northland might be introducing a foreigner to the environment — if the kauri came from the Coromandel, as small genetic differences within the same species occur in different districts. The 'purest' source of native vegetation is from locally sourced seeds. A counter-argument could certainly be made that it does belong, however, as fossil kauri has been found much further south. It was probably the climate changes of the Pleistocene that wiped them out further south, hence planting kauri south of its current range may not be introducing a foreign species but rather re-introducing a locally extinct native!

right **Native ferns and angiosperms thriving in a pine forest near Anaura Bay, Gisborne District.**

opposite **A beautiful place which must rate a mention, Eastwoodhill Arboretum's superb collection of exotic trees from around the world was planted on the hills behind Poverty Bay, Gisborne District, initially by William Cook (who died in 1967).**

MANMADE ENVIRONMENTS

A detailed look at the ecology and future of manmade environments is beyond the scope of this book, but together they have contributed much to the look of northern New Zealand. They provide both home and income to almost all its human inhabitants and are an essential although very recent part of the story of our flora and fauna.

EXOTIC FORESTS

Exotic forestry has become very common in northern New Zealand, the largest of which is New Zealand's largest pine plantation, the Kaingaroa Forest. The most commonly planted pine by far is the Monterey pine (*Pinus radiata*), although it has been selectively bred to improve the quality of its wood and the modern plantation tree little resembles the Californian native. Pine plantations are concentrated in the central volcanic area between Lakes Rotorua and Taupo and to the east of this area, on the less fertile Kaingaroa Plateau, but are also scattered throughout northern New Zealand, especially on hill country. They have also been extensively planted to stabilise the west coast sand dunes as well as in the steep, erosion-prone hillsides of the Gisborne District (the East Coast Forestry Project), as a defence against erosion such as has occurred on a massive scale at places such as Tarndale. Although pine plantations are the most common of the various exotic forests, there are also large plantings of other exotic trees, such as in the Whakarewarewa Forest near Rotorua.


Pine forests, especially those in our more pluvial climates, develop a sophisticated native understorey over time, often most notably including the mamaku (*Cyathea medullaris*) and silver fern (*C. dealbata*), tree ferns in the moist gullies as well as a ground layer of ferns; subcanopy trees also begin to develop once the light levels diminish at canopy closure (once the pines are aged around 10–15 years), as they can then outcompete earlier exotic species such as gorse, broom and grasses. If left long enough, it might be that pine forests will become dominated by native vegetation and the pines will die out, but the 25- to 30-year felling cycle of pine forests usually precludes maturation of a native subcanopy. Naturally, pine trees can easily live for more than 100 years. Such forests can provide important habitat for native species; for instance, the Waitangi Forest in the Bay of Islands supports a population of around 1000 North Island brown kiwi (despite hundreds having been predated by a lone dog in 1987), Hochstetter's frogs (*Leiopelma hochstetteri*) live in some Northland pine forests, kaka (*Nestor meridionalis*) love the bark of Whirinaki's Douglas fir (*Pseudotsuga menziesii*), and Monterey pine cones may yet prove a valuable food source for kakapo. The Iwitahi Orchid Reserve in the Kaingaroa Forest likewise supports 36 species of native orchid, and insects such as weta, ghost moth caterpillars and the huhu beetle (*Prionoplus reticularis*) also like some exotic forests. Streams are protected from overheating and eutrophication by the shade of the trees, and freshwater fauna such as giant kokopu (*Galaxias argenteus*) and short-jawed kokopu (*G. postvectis*) may also flourish; often in the gullies through which they run, a native riparian margin is left which adds to the value of such streams.

Pine plantations are clearly a much better nursery for our native flora and fauna than dairy farms, which at the moment appears

to be the land use most attractive to many land-owners. However, pine forests in drier areas (the classic example being outside northern New Zealand, in Canterbury) do not support as much undergrowth and the main birds in such forests are the insectivores as nectar and fruits are in short supply. They also do not provide suitable habitat for many species, such as hole-nesting birds. Hence, although somewhat better than dairy farms they are definitely second best to native forest. Further, they also get demolished every 25–30 years, although the practice of having a patchwork of trees, each at a different level of maturity and age (some recently cleared, some young trees and some almost ready to be felled) in the forest does aid native life. Not all pines are good; some, both Monterey and lodgepole pines (*Pinus contorta*) as well as Douglas fir have escaped into areas of native non-forest vegetation, due to their ability to survive in such environments, and in the long run may supplant our own vegetation in other areas; such pest pines are termed wilding pines. They may also survive in regrown native forest for a very long time, for instance in the Waioeka Gorge.

FARMLAND

Much of the north, particularly the lowlands, has been transformed into farmland. Within it, patches of native forest and wetland communities may survive — often, however, the native species content of such areas is depauperate and continuing assaults, such as stock grazing on tree seedlings, may imperil their continued survival and in time result in their complete disappearance. A few native species, such as the New Zealand falcon and grass grub, have succeeded in colonising farmland, but the overwhelming proportion of species in such habitats are introduced. However, many farmers are aware of this threat and treasure these remnants, putting in place measures such as fencing to exclude stock from wetlands and forest remnants as well as reserving them for all time using Queen Elizabeth II covenants.

CITIES

Compared with farmland, towns and cities may actually not appear all that bad; there are a lot of plants growing in backyards, increasingly often native, and many local groups restoring local ecosystems, such as Project Twin Streams in the Waitakere area of west Auckland. Species that are used to colonising cliffs are also pre-adapted to colonising city buildings. However, scratch the surface and the truth is not as good; despite the parks and backyard greenery, there is a relative paucity of trees and hence berries and nectar for birds such as tui; food for native insects is also relatively sparse, leading to a concomitant decrease in insectivorous birds. At the same time, food waste encourages opportunistic, usually introduced, animals — insects such as wasps and houseflies (which, luckily, can be incorporated into the food chain when caught by spiders), cats, mice and rats and opportunistic birds such as finches (the most common being the chaffinch *Fringilla coelebs*), house sparrows (*Passer domesticus*) and mynas (mostly confined now to the north).

Further, humans have a disturbing tendency to want to beautify their surrounds with pretty flowers. Since New Zealand has a relative lack of such flowers, many have been imported only to escape and become invasive. In a similar vein, urban humans also have a love of pet animals, the predatory cat and dog in particular. This has been a subject of some debate recently, thanks to the philanthropist Gareth Morgan's 'Cats to Go' project, but not all of us are sufficiently vigilant about

neutering them and even the neutered ones are perfectly capable of killing.

The climate in cities is also different; all the heat emitted by cars, building heating and the latent heat trapped in concrete and brick keeps cities up to 5°C warmer at night in winter, enabling species that are temperature-sensitive to survive — including some introduced species that wouldn't otherwise get a hold here. Conversely, the noxious fumes of pollution must be coped with, favouring more-tolerant species over others.

CLIMATE CHANGE

In 2007, the Intergovernmental Panel on Climate Change (IPCC) projected an average global temperature rise of between 1.1°C and 6.4°C in the decade 2090–2099 compared with 1980–1999. Were this to happen, this would make New Zealand a more hospitable environment to more tropical species — but some of our native cold-adapted species might not be able to survive in such an environment.

CHAPTER FIVE:

THE FORESTS OF THE NORTH

INTRODUCTION

New Zealand has forests like nowhere else in the world, with 43 endemic vascular plant genera. It is not an exaggeration to say that the forests of northern New Zealand are the most splendid of all; in particular, the warm-temperate forests of its northern lowlands comprise the most complex and diverse forest type in New Zealand, with more than 100 endemic trees and shrubs including such iconic trees as the kauri and the pohutukawa, festooned in a jungle-like profusion of tree ferns, lianes and epiphytes.

Typically, warmer climates have a larger range of species than cooler climates. For instance, Samoa has a similar number of plant species to New Zealand, despite being about the same size as the Coromandel. Endemism in monocot and gymnosperm trees and shrubs, ferns, orchids and lianes is highest in the north. That said, the far south (Otago/Southland) is diverse in other ways, with increasing endemism of herbs, grasses and rushes as one goes south; the Nelson/Marlborough/Cook Strait region is also a 'hot-spot' of diversity and endemism. The north of the north, the upper south and the deep south have all been relatively geologically stable and subaerial for a long period of time. Conversely, the more southern parts of the North Island are geologically rather young and the Canterbury/Westland region lost much more of its vegetation during the glacial periods of the Pleistocene than did areas to the north or south of it, since the latter regions were less completely covered by ice and surrounding frigid tundra during that time (despite Otago's more southerly location). Hence, another reason for our diversity is the amount of time that there has been for species to diverge into all the various niches we have. Finally, just as New Zealand itself has a high degree of endemism, places such as the Surville Cliffs

portion of North Cape and offshore islands (e.g. the Three Kings Islands), isolated by either ultramafic geology or water, have higher degrees of endemism compared with other parts of the country.

Conversely, despite being highly endemic (82%) at the species level, only 65 of 446 New Zealand genera are endemic and there are no endemic families. There are also substantial numbers of genera with few New Zealand species in them. It would appear that the vast majority (if not all) of our flora came here relatively recently, over the last 26 Ma (since the Oligocene 'drowning'). Many of our plants also appear to hybridise with close or distant relatives relatively easily. In general, we have a relatively adaptable and robust flora, perhaps because of our recent very active tectonic history, which has probably both made new habitats available and destroyed others very suddenly.

top **Inside a kauri-hardwood forest of the north, a five-layered jungle-like profusion of trees and smaller plants. Waitakere Ranges, Auckland.**

bottom **Once northern New Zealand was almost completely mantled in forest, except for high peaks above the treeline (visible here) and lowland wetlands. Vast tracts still remain, particularly in the more difficult terrain. Raukumara Range, Gisborne District.**

Unfortunately the arrival of humans, both Maori and Pakeha, led to wanton destruction, particularly of lowland forests. As a result, the current distribution and relative abundance of different forest types is a product as much of man as of nature; indeed, we are still trying to understand what Polynesian fires destroyed. When Kupe and, later, Captain Cook arrived on our shores they were probably far more impressed by the magnificent kahikatea forests of the lowland Hauraki Plains and Bay of Plenty than by the rimu–tawa forests of Whirinaki, although the latter are one of our greatest treasures. What survives is a biased selection mainly based on the accessibility or otherwise of the native forests to earlier settlers of both races and the usefulness of the land for agriculture. An excellent example in Northland is the way the puriri (*Vitex lucens*) forests around Lake Omapere, on prime agricultural land, are almost gone, yet the adjoining Puketi and Omahuta forests, on an uplifted and less useful block of terrain, contain almost as natural a forest as one can find.

We also have many areas dominated by smaller trees such as manuka (*Leptospermum scoparium*), kohuhu (*Pittosporum tenuifolium*) and various shrubby hardwoods, created either by humans clearing the land for timber or agriculture or by natural disasters, including fires, gales and landslides, which have not reverted yet to 'climax' forest.

top **A relict, solitary karaka *(Corynocarpus laevigatus)* survives in farmland above Tolaga Bay, Gisborne District. Karaka were also planted by Maori outside their original range (the northern North Island), probably as a food source.**

bottom **The forest cover of northern New Zealand is dark green in this satellite image. The majority is native, the biggest exceptions being extensive pine plantations just east of a line joining the Rotorua lakes and Lake Taupo (the Kaingaroa Forest) and near the Gisborne District, but small exotic plantations are dotted throughout. Note how it is the upland areas that have retained their forest cover. Map data: Google. Imagery ©2014 NASA, TerraMetrics.**

ENDEMIC PLANT SPECIES

Many of the species found in northern New Zealand are endemic to that area, i.e. only found there. Some, such as taraire (*Beilschmiedia taraire*) and puriri, are common here but unknown elsewhere in New Zealand in a natural state; others are known from just a few isolated plants, an example being the white-flowered rata of

Te Paki (Bartlett's rata, *Metrosideros bartletti*). Some of these genera, including *Dysoxylum*, *Meryta* and *Pisonia*, thrive only in the north because they are cold-sensitive. There are other reasons, however. Toatoa (*Phyllocladus toatoa*), which thrives in our cooler montane forests but is absent further south, follows infertile soils rather than climatic zones. Many endemics also have close relatives that are common further south and at altitude — e.g. the northern towai (*Weinmannia silvicola*, also known as tawhero) cedes dominance to its close cousin kamahi (*W. racemosa*) as one goes south; so too does taraire give way to tawa (*B. tawa*).

There are also several species found both in the northern half of the North Island and the northern or northwestern South Island, in particular the Tasman District, but not in the southern North Island. The Tasman District and Nelson City area is the warmest part of the South Island and also has been around as dry land for a long time, unlike the southern North Island, which has meant that it has retained species that perhaps have just not yet colonised younger parts of New Zealand, although whether that is the whole explanation is debatable. Examples of such tree disjunctions include the kawaka (*Librocedrus plumosa*), a native cedar, which grows from Doubtless Bay to Awakino but is also present in Tasman District; and *Metrosideros parkinsonii* which is confined to the cloud (montane) forest of Little and Great Barrier islands but is also found in Tasman District and down the West Coast almost to Hokitika. Silver pine (*Manoao colensoi*) prefers high-rainfall areas in Northland and the Central Volcanic Plateau, being relatively common on poorly drained, leached infertile soils of the Central Volcanic Plateau and the West Coast of the South Island but generally scarce elsewhere. Interestingly, silver pine seemed to be much more common in northern New Zealand during the Pleistocene. Tawheowheo (*Quintinia serrata*) and tanekaha (*Phyllocladus trichomanoides*) are also both found in the northern North Island and northwestern South Island (tawheowheo as far south as Fox Glacier), but not in the southern North Island.

Some animal species share this disjunct distribution, such as the sooty beech scale (*Ultracoelostoma assimile*), which occurs from Taupo north and in the northern South Island only.

Some liverworts and mosses also have a disjunct distribution, living only in Northland (especially Waipoua), Auckland and the Coromandel as well as Westland, Fiordland and Stewart Island, probably because of climatic similarities.

TREE TYPES

To attain a tree-like size, plants had to evolve a vascular system (xylem and phloem) to enable them to conduct minerals and water throughout. Such plants are variously called tracheophytes, vascular plants or higher plants. Gymnosperms and angiosperms, the seed plants, represent the most recently evolved tracheophytes; these are the trees that dominate our forests, particularly the upper layers, although other vascular plants include ferns and clubmosses. Clubmosses are perhaps the most similar to the first vascular plants.

Conifers (softwoods), the most abundant of the gymnosperms, are cone-bearing seed plants. They include podocarps, kauri (*Agathis australis*), the native cedars (the aforementioned kawaka and kaikawaka, *Librocedrus bidwillii*) and celery pines such as toatoa. Conifers dominate the extensive boreal forests of the Northern Hemisphere; our conifers are often grouped together with others of the Southern Hemisphere as 'southern conifers'.

Hardwoods are angiosperms, i.e. flowering seed plants. They evolved later than gymnosperms, in the Middle Cretaceous, and are now the most diverse plant group worldwide. In general, New Zealand hardwoods are smaller and shorter-lived than our conifers.

Conifers compete well under dry and cold conditions and are often present as emergents above a hardwood canopy. However, they are often excluded completely from beech forests, especially those of the montane South Island. Northern rata (*Metrosideros robusta*) often attains heights comparable with the conifers.

FERNS AND TREE FERNS

New Zealand has around 200 native species of fern, around half being shared with other areas, particularly southeastern Australia. There are another 40 or so introduced species. Although also vascular plants, they reproduce by means of spores rather than seeds and require free water for fertilisation of the egg; hence they are more commonly found in damp places. Two genera, *Cyathea* and *Dicksonia*, have between them 10 species that can assume a tree-like form (i.e. are arborescent); two common species are the silver fern (kaponga or ponga, *Cyathea dealbata*) and the rough tree fern (wheki, *Dicksonia squarrosa*). This diverse and abundant range of ferns gives a distinctly New Zealand feel to our forests that is not present in the Northern Hemisphere's temperate forests.

Other notable New Zealand fern genera include:

- *Asplenium*, e.g. the hen and chicken fern, mouku (*A. bulbiferum*)
- *Blechnum*, e.g. the crown fern (*B. discolor*), which often dominates the forest understorey
- *Gleichenia*, e.g. the common tangle fern (*G. dicarpa*)
- *Polystichum*, which includes the shield fern (*P. neozelandicum* subsp. *zerophyllum*), replaced north of about Taupo by *P. neozelandicum* subsp. *neozelandicum*
- *Cardiomanes*, which has as its sole representative in New Zealand, *C. reniforme*, a widespread native fern with kidney-shaped leaves
- maidenhair ferns, including the common maidenhair (*Adiantum cunninghamii*)
- the button fern (*Pellaea rotundifolia*), which is an endemic often cultivated as a garden or house plant
- *Leptopteris*, with the crepe fern (*Leptopteris hymenophyllioides*) being the most common in northern New Zealand.

left **Tree ferns dominate the lower layers in this low-altitude, predominantly rimu–tawa forest. Pirongia Forest Park, Waipa District.**

The limestone country of the western Waikato is the best place to find king fern or para (*Ptisana salicinia*), often growing in association with parataniwha (*Elatostema rugosum*) and supplejack (*Ripogonum scandens*). It is a large, robust fern with a tropical appearance and fronds up to 5 m tall with a starchy base that was a traditional Maori food source. It is also found in Australia and many South Pacific islands. Bracken (the Australasian and western Pacific species being *Pteridium esculentum*) is a common pioneering species which covered large areas of the Waikato basins left bereft of forest cover by Polynesian burning. Both these two fern species are the sole representatives of their genus in New Zealand.

NIKAU

Nikau (*Rhopalostylis sapida*) is our only native palm; its natural occurrence on Pitt Island at 44°18' S latitude makes it the highest-latitude palm in the world (i.e. growing furthest from the equator). It is particularly common in coastal and lowland locations, reaching its altitudinal limit in the Coromandel at 500 m. The species name *sapida* means edible; the growing tip at the base of the fronds is indeed edible, but this is the only growing point on the plant and, once removed, the plant dies.

left **The true maidenhair fern, *Adiantum aethiopicum*.**

below **Coastal forest with abundant nikau. Rangiwhakaea Bay, Great Barrier Island, Auckland.**

CHARACTERISTICS OF OUR FLORA

JUVENILE FORMS (HETEROBLASTY)

New Zealand's plants are particularly notable for the large number which have a juvenile form that is quite different to their adult appearance (which means that, to recognise a plant, you may need to learn two different forms). Some are tangled divaricating shrubs in their youth; others have larger, longer or more complicated leaves in their youth. Examples of the latter include raukawa (*Raukaua edgerleyi*); pate (*Schefflera digitara*), which is unusual as the different juvenile leaves are only present on some plants and only in the north; towai; kamahi; *Ackama* and *Dracophyllum* species; and several conifers, including silver pine, kahikatea (*Dacrycarpus dacrydioides*) and monoao (*Halocarpus kirkii*) — the juvenile leaves of these conifers are still small but in the adult they are further reduced to just scales. Lancewood (*Pseudopanax crassifolius*) probably has the most dramatic change, from the long, narrow juvenile state to the broad, erect adult condition; pokaka (*Elaeocarpus hookerianus*) leaves and those of turepo (small-leaved milk tree, *Streblus heteophyllus*) change in a similar although less dramatic fashion.

DIVARICATING SHRUBS

Not only juvenile trees but a large number of New Zealand shrubby plants assume a divaricating habit, with stems branching at large angles, seemingly intertwining every which way into a tangled mass. It has been suggested that this might be an adaptation to deter browsing moa, with many of those

left **Lancewood; the smaller juvenile forms are beneath a large adult. Pureora Forest Park, Ruapehu District.**

top ***Muehlenbeckia complexa*, a divaricating plant. Omaha, Auckland.**

bottom **One of our few deciduous species, tree fuchsia, high on Mt Pureora (one of our coldest parts, being both high and south) and surrounded by a cool-temperate montane forest smothered with ferns and moss-draped kamahi. Ruapehu District.**

that assume this growth form changing their stature, leaf shape and habit once they have grown high enough to be out of the reach of moa. However, there are other explanations — for instance, that this development is an adaptation to protect leaves against cold, wind, drought and frost or a way to maximise light exposure at different levels in the forest.

MIMICRY

Banks' toropapa (*Alseuosmia banksii*) is an untidy, fragrant and often lianoid shrub which grows in both lowland and montane forests. It belongs to a genus that seems to specialise in mimicry; for instance, it has forms which look exactly like ramarama (*Lophomyrtus bullata*), toru (*Toronia toru*) and tawheoweho.

EVERGREEN VS DECIDUOUS

Very few native trees are truly deciduous; of those that are, only lowland ribbonwood (*Plagianthus regius* subsp. *regius*) and tree fuchsia (*Fuchsia excorticata*) are common in the upper North Island.

OTHER CHARACTERISTICS OF NEW ZEALAND FLORA

Other characteristics of our flora include the following.

- There are few annual herbs and grasses.
- Hybridism is common (for instance between totara species).
- Very few have defences against mammalian browsers.
- Few are fire-adapted.
- More than normal (around 12–13%) are dioecious: that is, they have separate male and female plants, to avoid self-pollination and lack of variation in the next generation as well as to increase the viability of seeds. Such plants may recover more slowly from damage to the environment, however, as more than just a single tree is needed to propagate. Carlquist notes that dioecism is relatively common in the Hawaiian Islands and suggests that plants have adopted this mechanism because inbreeding is

more of a problem on islands, since they were normally only colonised by a few individuals which remained cut off from the rest of their species.

- Flowers are typically small and white; this is in keeping with the indigenous pollinators being relatively general (such as flies, our relatively primitive short-tongued bees, small birds and even the wind) rather than specific to certain plants, although there are exceptions — including the bright yellow flowers of kowhai (*Sophora* species), the summer red of pohutukawa (*Metrosideros excelsa*) and the year-round puriri. Only about 1% of New Zealand flowering plants are clearly adapted to avian pollinators.

- Some genera, such as *Coprosma*, have undergone wide adaptive radiation to exploit multiple ecological niches.

- Plasticity, where plants adopt different characteristics under different environmental conditions, is a feature of some New Zealand plants, including hangehange (*Geniostoma ligustrifolium*), a coastal and lowland shrub.

FOREST TYPES OF THE NORTH

Our lowlands, which include all of Northland and are where almost all the human population lives, is dominated by warm-temperate forest; forest containing kauri is present in the northern half. As one travels towards the coast, trees tend to become stunted by exposure to winds and salt spray; some disappear altogether while others thrive in the milder temperatures, as ‘coastal forest’. In a similar fashion, plants that cope better with waterlogged ground dominate ‘swamp forest’.

Nicholls and McKelvey and Nicholls have described the distribution of the various forest associations throughout the North Island and this forms the basis of my descriptions of each forest type, although modified.

Higher up, as well as further south, temperatures decrease (by about 1°C every 200 m above sea level), rainfall increases, especially on windward slopes, and frosts become more severe. As a result the forest changes at around 700 m altitude to a cool-temperate (montane) forest with a different collection of plants; starting at about 700 m up the most northerly hills of sufficient altitude, such as Te Moehau in the Coromandel, the dominant forest species change to either a podocarp–hardwood mix such as Hall’s totara (*Podocarpus cunninghamii*; also known as thin-barked totara) and kamahi (*Weinmannia racemosa*, which, in the South Island, forms forests at sea level), or beech, or a mixture thereof.

The upper margin of this type of forest is considered to be the upper limit of kamahi, red beech (*Fuscospora fusca*), lianes and vascular epiphytes, beyond which lies a subalpine or upper montane belt of either silver beech (*Lophozonia menziesii*) or mountain beech (*Fuscospora cliffortioides*) or, where beech is absent, a dense tree-heath 1–2 m tall. This margin occurs at an altitude that has a January mean air temperature of around 11°C. The beech treeline occurs abruptly, approximately where the mean January air temperature is 10°C and close to 7°C for a 6-month growing season.

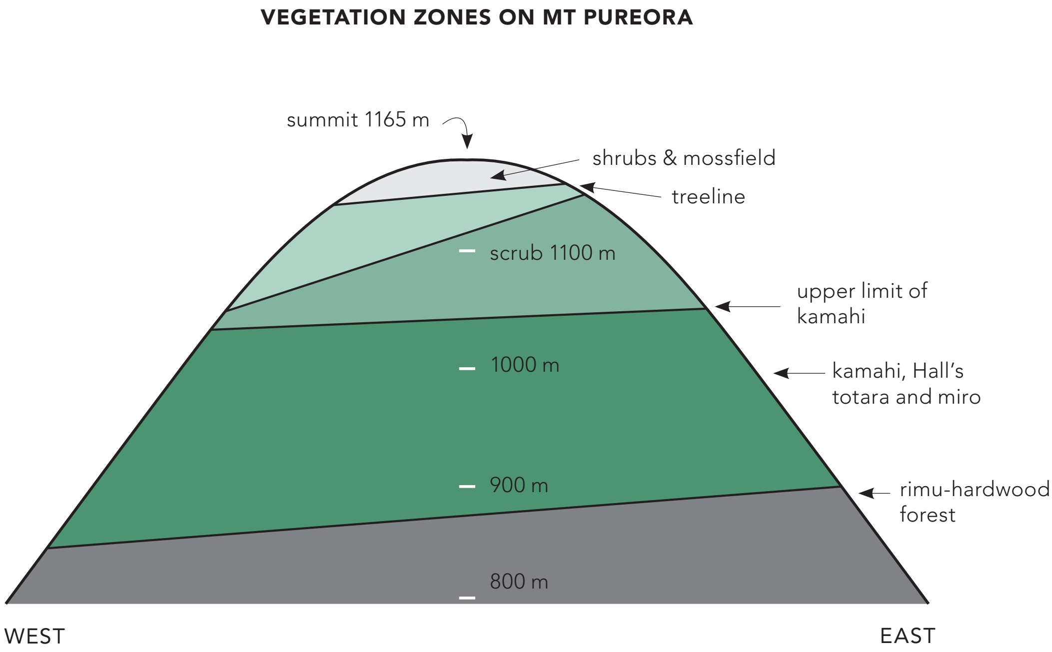


Figure 1 **Altitudinal zones on Mt Pureora, Ruapehu District. The change from a warm-temperate to a cool-temperate podocarp–hardwood forest is marked by a change from rimu- and tawa-dominated forest to one dominated by kamahi and Hall's totara; the treeline is marked by the upper limit of emergent thin-barked totara.**

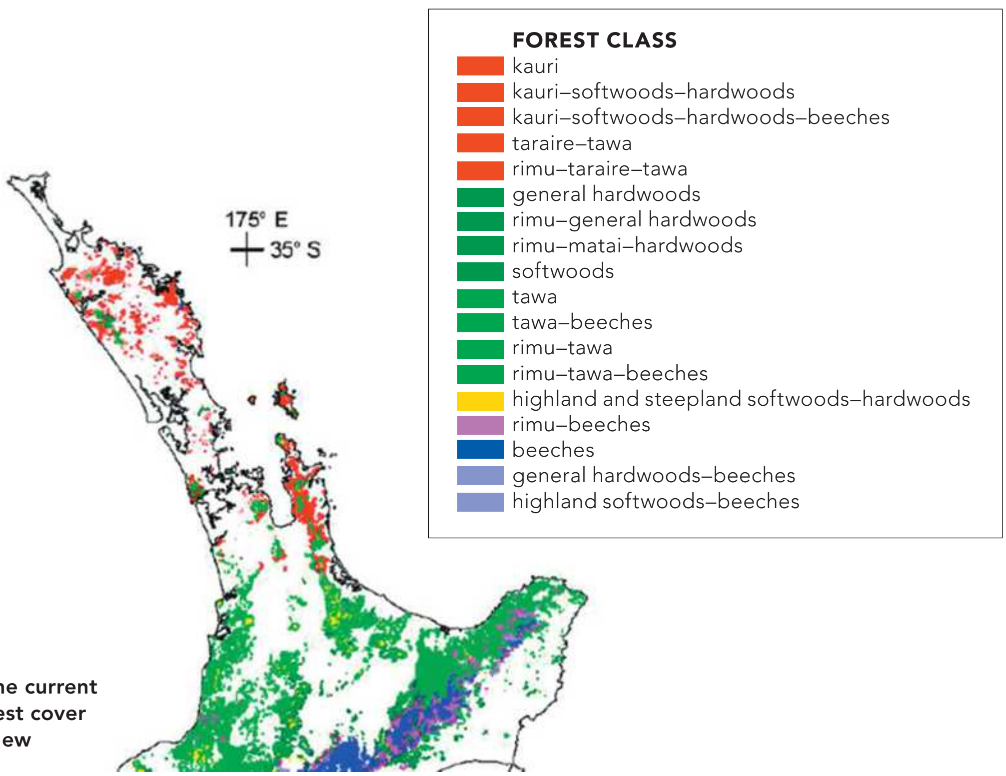


Figure 2 **The current native forest cover of north New Zealand.**

Offshore islands often have a slightly different forest composition from the mainland. They frequently lack certain tree types, presumably because those particular trees haven't managed to reach that island since at least the end of the Pleistocene; and, being maritime, they have more coastal species (see below). Conversely, they provide a refuge for some plants that are subject to intense grazing pressure on the mainland, such as the highly palatable herb colensoa (koru, *Colensoa physaloides*), formerly common in Northland kauri forests but now more readily seen on islands such as the Poor Knights, Hen, Three Kings and Rakitu islands as well as some inaccessible mainland locations such as cliffs.

LOWLAND WARM-TEMPERATE FORESTS

The dominant forest type of the lowland upper North Island is a conifer–hardwood forest, sometimes dominated by podocarps and sometimes by hardwoods, occasionally even to the complete exclusion of the other; the more northerly include kauri. The exact composition of such forest can vary substantially even over small distances, depending on the landform, height, soil, history of the vegetation in that area and other factors. For instance, on one northern hill one might find kauri high up on the ridges, taraire, northern rata in the bumps and nikau in the gullies, while another nearby may have kowhai (*Sophora fulvida* or *S. longicarinata*) on a similar ridge (although admittedly not particularly commonly), taraire and mamangi (*Coprosma arborea*) down on the slopes and kahikatea in the hollows.

THE TROPICAL CONNECTION

Our lowland temperate rainforests have a number of similarities to tropical rainforests, including the following.

- Five layers of trees, rather than the three normally found in the Northern Hemisphere temperate zone; similar forests, often with related species, exist in other parts of the Southern Hemisphere's temperate zone, including central Chile, southeastern Australia and southeastern South Africa, although for its latitude our forest is particularly blessed with an abundance of vines and epiphytes. Fossils of similar temperate rainforests have been found in the Northern Hemisphere, including in the vicinity of London (United Kingdom) as well as in Oregon (United States of America). It is therefore possible that this forest type was more common in the Northern Hemisphere but was almost eliminated from that part of the world, except in southern Japan and parts of China, by the severity of the Pleistocene glacial periods in those locations; our moderate marine climate could have enabled such forest types to remain extant here. The temperate rainforests in coastal Washington and British Columbia have a very different character.

- Plank buttresses in some trees that grow in swamps (pukatea, *Laurelia novae-zelandiae*).

- The presence of pneumatophores (found in pukatea, swamp maire [*Syzygium maire*] and kiekie [*Freycinetia banksii*] as well as the coastal mangrove [*Avicenna marina* subsp. *australasica*]), prop roots (swamp maire) and column roots (aerial roots that attempt to run down to the ground, found in pohutukawa).

- Cauliflory (where flowers arise directly from the tree trunk), found in kohekohe (*Dysoxylum spectabile*), and some *Streblus* species, and the less extreme ramiflory (where they arise from branches), e.g. *Melicytus* species, *Tecomanthe speciosa* and *Metrosideros* subgenus *Mearnsia* species.

- We have the world's most southerly palm, the

nikau, particularly common in Northland and low-altitude coastal locations.

- Our tree species, even those more typical of montane forests, are generally not as cold-tolerant as those in the Northern Hemisphere.

- Protection of immature leaves during winter is also uncommon in our plants (exceptions include trees of the genus *Metrosideros* as well as *Pittosporum* and, in beech forest, *Fuscospora* species and silver beech).

- Large leaves are also a feature of a tropical rainforest and those with such affinities in our area, such as puriri, may display that characteristic.

- Pulvini, joint-like thickenings at the base of leaves or leaflets that can stretch without breaking, tend to be a feature of tropical species (because of their larger leaf size) but are also found in kohekohe, puriri, turoa onamata (*Ackama nubicola*) and *Pisonia brunoniana*. Some tree genera found here and in more tropical climes may have evolved here and spread overseas, such as *Agathis* and *Metrosideros* subg. *Metrosideros*. Other species that have come here from warmer climes have obtained a foothold due to a 'species vacuum' here; for instance, eastern Australia has 14 species of *Litsea* while we have a solitary, very tolerant, wide-ranging species (*L. calicaris*) which shows few set ecological preferences within its range.

below **The buttressed roots of pukatea. Maungatautari Ecological Island, Waipa District.**

On the other hand, overall the leaves of our plants tend to be smaller than in tropical forests and the percentage of leaves with smooth margins is smaller; drip tips are also less common.

LAYERS OF A WARM-TEMPERATE FOREST

One can divide forest into various layers; lowland forests are the most diverse and have a maximum of five such layers, all adorned with epiphytes and vines. Other forests and shrublands may have fewer layers, but the names and general principles remain the same.

The emergent layer (30–50 m)

The tallest trees are predominantly conifers, kauri and/or the large podocarps. In some forests there may be just a few scattered emergents whereas in others (e.g. some of Northland's kauri forests) the 'emergents' may actually form a complete canopy at this height. Some angiosperms may also be found at this level, notably northern rata and pukatea. Rewarewa (*Knightia excelsa*) is also common on hill slopes as an emergent, although usually in relatively young forests. These plants get the most sunlight but endure the most variation in climate.

The canopy layer (approx. 20 m)

The layer immediately below the emergent, this tends to have a greater number of trees in it, although the more the emergent trees form

a closed canopy, the more sparse this layer becomes.

Predominantly hardwoods, this layer is dominated by trees such as taraire, puriri and white maire (*Nestegis lanceolata*) in the North Auckland and Coromandel peninsulas. In the far north, kohekohe, a cold-sensitive tropical-looking tree with large leaves, can be co-dominant.

Further south and at higher altitudes (above about 450 m), tawa and in Northland towai predominate. Tawa is possibly the most abundant hardwood in the north; it is a large tree, capable of reaching 35 m in height, with a refreshingly light-green colour to its leaves. Other canopy trees may include hinau (*Elaeocarpus dentatus*) and the smaller conifer tanekaha, which grows to about 25 m. There is also a cousin of hinau, pokaka (*E. hookerianus*), which is sometimes present in riparian forests in the North Auckland Peninsula and becomes steadily more common in these types of forests from about the northern Waikato south.

The subcanopy (10–15 m)

This layer consists of tree ferns and small trees, including our only native palm tree, the nikau, which is often very prominent

top **Inside a lowland conifer–hardwood forest, near its upper altitudinal limit. The large, lighter trunks in the background belong to emergent rimu while the smaller, almost black trunks are those of canopy-forming tawa. Smaller trees, their crowns well below the mature tawa, are visible in the foreground, contributing to the subcanopy, while a cluster of tree ferns forms the small tree–shrub layer. Just visible in the right foreground are crown ferns, representing the ground layer. Te Urewera, Wairoa District.**

middle **Rimu emergents. Whirinaki Forest Park, Whakatane District.**

bottom **The beautiful light-green colour one gets as light filters through a tawa canopy, Whirinaki Forest Park, Whakatane District. Note also the lower layers of the forest in the foreground and, in the background slightly left of centre, the trunk of an emergent rimu.**

in our forests (particularly in Northland), together with smaller hardwoods such as mahoe (whiteywood, *Melicytus ramiflorus*), pigeonwood (porokaiwhiri, *Hedycarya arborea*) and toro (*Myrsine salicina*), as well as the juveniles of larger trees.

Some of the larger tree ferns, including the black tree fern (*Cyathea medullaris*) and silver fern, can be found in this layer, especially in the lowlands and near the coast.

The plants that grow in the subcanopy are generally fast-growing and are often the first to colonise new areas or revegetate formerly cleared land, before the taller trees grow through and dominate them (forest with these trees as the highest layer is sometimes termed bush). Some subcanopy trees more commonly found in canopy gaps include wineberry (*Aristotelia serrata*), putaputaweta (*Carpodetus serratus*), kaikomako (*Pennantia corymbosa*, more common from Auckland south), our native deciduous tree fuchsia, lacebark (*Hoheria populnea*), *Pittosporum* species, lancewood (*Pseudopanax crassifolius*) and cabbage trees (*Cordyline australis*).

Shrub and small tree layer (3–8 m)

At a more human height, notable species found in this layer include tree nettle (*Urtica ferox*, ongaonga) with its stinging leaves, *Coprosma spathulata* subsp. *spathulata*

top **The subcanopy layer, here with nikau particularly prominent, is exposed under a predominantly rimu–tawa canopy and emergent layer as the Waioeka River cuts through the valley. Opotiki District.**

middle **Looking up into lowland conifer–hardwood forest near Opotiki; the subcanopy here is formed by tree ferns, their thin trunks rising quite a lot higher than the smaller plants, mostly ferns, of the shrub and small tree layer. In the background is a mix of the podocarps matai, miro, rimu, kahikatea and the predominant hardwood canopy tree, tawa. Opotiki District.**

bottom **Rangiora (*Brachyglottis repanda*). Morere Springs Reserve, Wairoa District.**

above **A dense, almost impenetrable shrub layer beside a small stream. Whirinaki Forest Park, Whakatane District.**

in northern lowland forests (the related *C. spathulata* subsp. *hikuruana* grows on ultramafic rocks in the vicinity of North Cape), the toxic tutu (*Coriaria*, six species) and rangiora (*Brachyglottis repanda*); the large leaves of the latter are also known as bushman's friend or bushman's or boy scout's toilet paper.

Some plants at the shrub and small tree level appear to have evolved ways of making themselves less desirable to herbivores, which can of course more easily reach this level, such as the hot-tasting leaves of kawakawa (*Piper excelsum*), a relative of the pepper plant.

The slightly smaller tree fern the wheki may also be present, along with five-finger (whauwhaupaku, *Pseudopanax arboreus*) in lighter places, the two karamu (*Coprosma lucida* and *C. robusta*), wharangi (*Melicope ternata*) and the tree daisy heketara (*Olearia rani*). Other trees may include hangehange, kanono or raurekau (*Coprosma grandifolia*) and pate.

Many of the smaller forest plants, although often overlooked by their more impressive neighbours, make a vital contribution to the forest ecology. For instance, the native brooms (*Carmichaelia* species) and kowhai (*Sophora* species) are legumes, plants that on their roots contain nodules of the nitrogen-fixing bacterial genus *Rhizobium*, which transforms atmospheric nitrogen into ammonia, thus making both their own and others' fertiliser. Tutu is a key driver of future forest as it is numerically more common than these plants in regenerating (seral) forest and its roots have nodules supporting *Frankia* (also nitrogen-fixing bacteria). These have been

supplemented by adventive legumes such as gorse which, not coincidentally, is not a bad nursery for native forest; we have relatively few nitrogen-fixing native species.

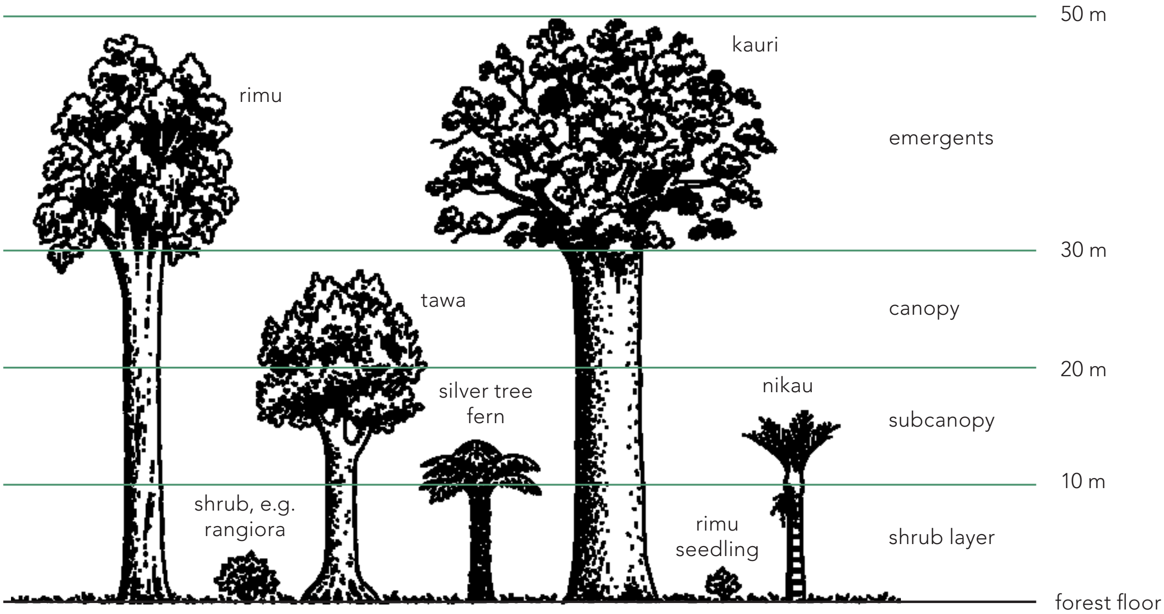
Ground layer (below 1 m)

Protected by all the other layers from extremes, the environment here is stable, constantly cool, dark and damp, so plants growing here must be shade-tolerant but do not have to cope as much with drying out or extremes of temperature. Usually dominated in our forests by ferns, this is also the habitat of small flowers (herbs, or non-woody small flowering plants, as well as ground orchids), grasses (both true grasses [Poaceae], and other tufted plants with long, narrow, parallel-

top **A dense groundcovering of parataniwha. Maungatautari Scenic Reserve, Waipa District.**

bottom **The ground level is here dominated by crown ferns, under a predominantly tawa canopy with scattered, mainly rimu emergents. Te Urewera, Wairoa District.**

Figure 3 **Diagrammatic representation of the various forest layers with representative plants at each layer.**



veined leaves such as kauri grass [*Astelia trinervia*]), mosses and liverworts as well as fungi (not a plant, of course) and lichens.

Wineberry may also be present, as may the grass *Microlaena avenacea*; in season, one can see *Corybas* and *Pterostylis* orchids and, often in moister areas such as shaded banks, parataniwha.

below **A look inside a five-layered lowland podocarp–hardwood forest. Note the tall, emergent thin-barked totara on the right, a canopy tawa on the left, a collection of subcanopy ferns in the centre, shrubs lower down and a relatively sparse ground layer (this reserve not being fenced against browsing animals). Te Maketu Historic Reserve, Ramarama, Auckland.**

KAURI FORESTS

The largest of all our trees, kauri forms forest in association with other conifers and hardwoods from the far north to just south of Kawhia on the west coast and to Te Puke on the east, although as late as 300,000 years ago (300 ka) kauri was present much further south than it is naturally found now. Presumably it retreated north during the glacial periods, as it can certainly survive even on Stewart Island; there is a beautiful large kauri beside Walter Peak station on Lake Wakatipu, near Queenstown. Since the most recent glacial period only ended about 10 ka, there may not have been enough time for kauri to naturally recolonise the more southerly areas that it is once again quite capable of growing in. Even in the north, it has been gradually becoming more common since the end of the Pleistocene and is probably gradually expanding in a southerly direction.

Kauri seems to establish relatively easily on infertile soils (which they further impoverish), such as the ridges of Northland, and it is on such ridges that much of the remaining kauri can be found; in the more fertile valleys, podocarps often predominate. However, kauri's obvious suitability to these relatively flat areas and their known historical abundance on river terraces and coastal plains, well attested to by the presence of old kauri logs known as swamp kauri which may be found in some low-lying lands in the north (such as around Kaitaia) from where they are excavated and used for their timber, suggests that the current 'range and hill' populations could reflect logging rather than kauri's preferred location.

Nevertheless, the largest, most continuous and most well-developed of the remaining kauri forests are found on Northland's upland volcanic plateaux, in particular the Waipoua, Puketi, Trounson and Omahuta forests.

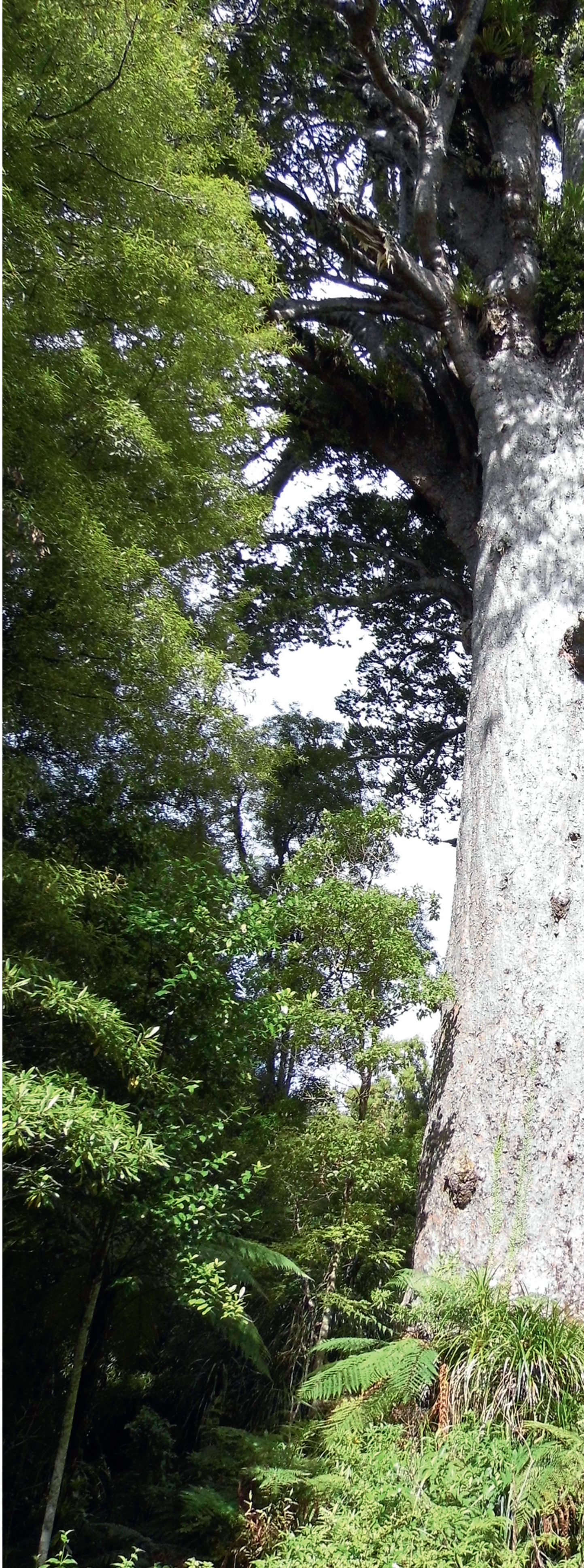
More common are forests where kauri is

above **Kauri almost completely dominates the steep ridge in the background, forming a closed canopy at the emergent layer, but is partially displaced by emergent podocarps, including rimu, totara and kahikatea, in the valley. Waitakere Ranges, Auckland.**

right **Tane Mahuta, the largest kauri left alive. Waipoua Forest, Far North District.**

found either in scattered groves or singly, the rest being dominated by other soft- and hardwoods; often this is the result of logging. Such forests can be found up to about 800 m in the Coromandel and in other scattered locations throughout northern New Zealand and are the most common forest type north of a line joining Hamilton to the Kaimai Range, although scattered kauri groves can be found down to kauri's southern limit just south of Kawhia and near Te Puke. Although the largest kauri are currently found in western Northland, historical records show that prior to logging the largest kauri were once found on the Coromandel Peninsula, where there is still significant kauri forest.

Kauri is also common in the Waitakere, Hunua and Hakarimata ranges as well as on Great Barrier Island; isolated stands are present down the west coast as far as Kawhia and to Te Puke in the east as well as in the Lower Waikato Basin, although kauri has



been logged almost out of existence in the Hamilton Basin and was never a feature of the Hauraki Plains. Regrowth of previously logged kauri forest has in some places been very vigorous; for instance, poles of kauri rickers are very visible to the multitudes of Aucklanders and visitors as they travel the Northern Motorway between Orewa and Puhoi.

KAURI THE TREE

Kauri preserves an ancient lineage that stretches well back into the time when New Zealand was part of Gondwana, and its family, the Araucariaceae, has been around for 250 million years (Ma). Other members of the family Araucariaceae include such trees as the Australian bunya-bunya tree (*Araucaria bidwillii*), the recently rediscovered Wollemi pine (*Wollemia nobilis*) of New South Wales, the oldest fossil of which has been dated to 200 Ma, the Cook pine (*Araucaria columnaris*) of New Caledonia, the monkey puzzle tree (*A. araucana*) of South America and the Norfolk pine (*Araucaria heterophylla*). All surviving members of this family are confined to an area that includes Indonesia, New Guinea, Australia, the southwest Pacific, Chile and Argentina, as well as New Zealand. *Agathis* itself can be found in Australia (consider the Queensland kauri, *Agathis robusta*), Indonesia, the Philippines, and the southwest Pacific as well as in New Zealand; the closest relation to our kauri is the Pacific kauri of Vanuatu, Fiji and the Solomon Islands (*Agathis macrophylla*).

Each kauri forest is unique to its particular location and kauri are always found in association with other species; in virgin forest, kauri dominated but did not monopolise the forest in the same way that, for instance, beech forest may be almost completely dominated by one species of that genus. Kauri often grew in scattered groves or individually,

above **A natural kauri–softwood–hardwood forest (i.e. one with just scattered kauri), Trounson Kauri Park, Kaipara District. Kauri and the occasional podocarp (kahikatea in particular) emerge above a hardwood canopy of taraire and tawa (a slightly cooler-climate tree) at 240 m above sea level.**

perhaps because it releases so few nutrients back into the soil, impoverishing it and in turn limiting the growth of young kauri and the recruitment of another generation around it; or perhaps because of its symbiotic relationship with mycorrhizal fungi and *Streptomyces* bacteria. Certainly kauri resin makes the litter under these trees sterile and infertile and, as a result, young kauri often appear to grow better under manuka than under older kauri, although sites have also been noted where generations of kauri have grown up one after another.

Kauri pollen is released to travel on the wind from the male cone around September to November; the fertilised female cone then ripens in early February, falling apart and releasing up to 100 winged seeds which can travel as far as 1.5 km from the parent, although usually more like 100–150 m. Ten to 20 days later the seed germinates; as mentioned, they tend to develop best under manuka, where there is some space and light, and establish better on soils with low fertility, possibly because of reduced competition. Initially young kauri grow between 10 and 25 cm per year into tall, skinny pole-like trees known as rickers. At around 25 years of age, they start to lose their lower branches; and then, at 40, when they are above most of their neighbours (they will become the uppermost layer of the forest at about 30 m), their upward growth slows and their girth starts to increase.

KAURI FOREST UNDERSTOREY

In western Northland's mature, almost continuous kauri forests, other emergents may include podocarps such as rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*) and Hall's totara (*Podocarpus cunninghamii*). Hall's totara is an interesting tree to find in such forests as most would usually think of it as a cold-climate tree; in truth it is just a very tolerant tree and grows in kauri forests because it is tolerant of their infertile soils. Tanekaha is often also found

below 450 m and kawaka is also common in such forest.

In the canopy layer, alongside younger trees of these same species, occur hardwoods such as taraire, rewarewa, tawa, hinau, northern rata, kohekohe, monoao, towai and tawari (*Ixerba brexioides*); the latter, like Hall's totara, is often found in association both with kauri and with montane forest (*Ixerba* is related to New Caledonia's *Strasburgia*, which often grows there alongside *Agathis*). Maire taiki (*Mida salicifolia*), a small hemiparasitic tree, may also be found in kauri forest (see the section on parasites), as can the small podocarp monoao which is abundant in Te Paki's Radar Bush, the Puketi Forest and on Great Barrier Island but absent from many other areas of kauri forest (and hence is considered 'at risk/naturally uncommon'); it would appear to thrive in areas of disturbance.

above **Mature kauri forest, showing only sparse vegetation beneath the almost closed canopy. Note, however, the widespread 'kauri grass' of the forest floor and the occasional small hardwood. Waitakere Ranges, Auckland.**

Other trees, more common outside the continuous kauri forests of western Northland, include puriri, members of the kanuka complex (*Kunzea* species) and, on the east coast of Great Barrier and the Coromandel, often abundant pohutukawa. Mamangi becomes more common as one heads south towards Auckland and the Waikato (its southern limit).

The more that kauri forms a closed canopy, the more sparse the layers below become; this often gives kauri forests quite an open, bright character.

The subcanopy and shrub layers may contain a wide variety of plants. Perhaps the

most characteristic are neinei (*Dracophyllum latifolium*), toro, mairehau (*Leionema nudum*) and kohurangi (*Brachyglottis kirkii* var. *angustior* and var. *kirkii*); other species often present include mangeao (*Litsea calicaris*), towai, makamaka (*Ackama rosifolia*), native honeysuckle (*Alseuosmia* species), shrub rata, mapou (*Myrsine australis*), five-finger, the tree ferns ponga and wheki, lancewood and nikau. A common coprosma in such forests is *Coprosma spathulata* subsp. *spathulata*.

Finally, on the ground, as well as seedlings of the more mature trees, are plants such as kauri grass, the giant sedge *Gahnia xanthocarpa*, toetoe (*Austroderia* species) and kiekie (*Freycinetia banksii*), as well as small ferns.

LATITUDINAL AND ALTITUDINAL CHANGES

With changing latitude and altitude the character of our kauri forests changes, and in the coolest such forests high in the Coromandel it has a much more cool-temperate look. These changes occur progressively; the more subtropical trees disappear first and are replaced by cooler-climate trees, in some cases relatives of the more subtropical trees. These changes include the following.

- Above 450 m in western Northland (particularly at Warawara, which is situated on a high plateau often above this altitude) the understorey becomes more sparse; rimu, miro, Hall's totara, hinau, towai and tawari are present but the less cold-tolerant rewarewa, kohekohe and tanekaha are absent.

- In mainland Auckland the more tolerant and widespread hardwoods tawa, northern rata and hinau are increasingly visible, although the subtropical rewarewa and kohekohe are also present. Podocarps common in the Auckland region include rimu, miro and Hall's totara. This forest can be found at its most abundant in the Waitakere Ranges, up to 350 m altitude; the only place that substantially exceeds this altitude in this region is in the Hunua Ranges.

- Puriri and taraire become less common with increasing latitude and altitude; taraire is absent from kauri forest in the Coromandel's southern half.

- On Great Barrier Island, above 350 m, monoao, yellow-silver pine (*Lepidothamnus intermedius*), toatoa and tawari are more common.

- Further south, in the Kaimai Mamaku Forest Park, the warmer-climate kohekohe and tanekaha can be found alongside trees such as tawari, kamahi and mangeao but disappear above 350 m.

- The Coromandel includes the highest summits in our northern half. There, above 550 m, cooler-climate trees including yellow-silver pine, southern rata, tawari and toatoa commonly grow alongside kauri, rimu, miro, Hall's totara and towai.

- Between 700 and 800 m such forest, still often including kauri, becomes stunted and consists mainly of yellow-silver pine, with toatoa, southern rata (*Metrosideros umbellata*), towai and tawari. This represents a rare mix of northern and southern species, found also in the Waipoua Forest, Hirakimata on Great Barrier Island and, although lacking yellow-silver pine, at Herekino, Warawara and Te Paki.

KAURI AND BEECH

One does not often think of beech and kauri forest in the same breath, but hard beech (*Fuscospora truncata*) grows as far north as

left **The unique forests of Little Barrier rise up above the boulder-strewn shore. Hauraki Gulf, Auckland.**

Mangonui and can be found in association with kauri in the far north, including in the Omahuta Forest; usually beech is subordinate. Further south, kauri and hard beech occur together on the southern edge of the Hunua Ranges; common also are the softwoods rimu, miro, Hall's totara and tanekaha, as well as *Kunzea* species. Auckland's now suburban North Shore was also once clothed in kauri–hard beech forest; traces remain in places such as Chatswood Reserve. This association can also be found locally in the Waitakere and Hapuakohe ranges and at Pukemokemoke in the Hamilton Basin, as well as in the Coromandel Peninsula. The possibility that hard beech is not replacing itself and is getting gradually overtaken by kauri has been raised, due to the finding of unhealthy trees in Auckland and Northland, although this was not supported by a study conducted in the Waikato's Hapuakohe Ecological District.

Little Barrier Island has the most intact kauri–softwood–hardwood–beech forest, with an altitudinal sequence stretching from shore to summit; kauri and hard beech are both present although not widespread, along with miro and the hardwoods rata, tawa, rewarewa, towai and tawari. However, there is no rimu, generally one of the most abundant podocarps. Hard beech is also present on Waiheke and Ponui islands but, interestingly, it is absent from Great Barrier Island; this may be due to the inability of its seeds to cross saltwater.

This association is also present in the Coromandel between 300 and 600 m, especially in the Kapowai Valley; tawa, hinau, rewarewa, towai and tawari are also common, as are the same softwoods found in the Hunua Ranges.

To the south of these forests, in the Kaimai Range and to the south of the Hunua Ranges, kauri and hard beech also occur together, again together with rimu, miro and thin-barked totara but this time most often alongside rata, rewarewa, toru (which grows from the coast up to montane forests, generally on infertile soils) and the cooler-

left **High in the Coromandel, on the side of the Pinnacles, kauri (centre, in background) is regenerating alongside yellow-silver pine (foreground) and rimu (left). Thames-Coromandel District.**

climate toatoa and kamahi.

Finally, at higher altitudes (600–700 m) in the Kaimai Mamaku Forest Park one can find both hard and silver beech, the latter at the northern edge of its range, in association with kauri; common other trees include cooler-climate species such as toatoa, kamahi, tawari and tawheowheo.

PODOCARP–HARDWOOD FORESTS

Encompassing those forests that neither contain kauri nor are predominantly beech, this is a very heterogeneous group of both warm- and cool-temperate forests, the distinction being usually made at the altitude where tawa cedes dominance to kamahi. They range from forests dominated by podocarps (softwood forests), through those with a hardwood canopy and podocarp emergents (podocarp–hardwood forests), to those composed solely of hardwoods. Overshadowed in the north by the great kauri forests, they are almost ubiquitous south of Hamilton, except in the higher parts of the axial ranges and the Kaimai Mamaku Forest Park where beech forests are the predominant cool-temperate forest type.

THE PODOCARPS

Podocarpaceae is an old and diverse southern Gondwana family; the main centres of species diversity are in Australasia (New Zealand, New Caledonia and Tasmania), South America and Malaysia/Indonesia, but podocarps are present as far north as southern Japan and China, Mexico and sub-Saharan Africa and India. The family dates back to the Jurassic and the lineages represented by rimu and kahikatea appear to have changed little over the last 70 million years.

In these species the seeds are usually held above a fleshy structure attractive to birds, which are the key means of their dispersal. While most species have a 'naked' fruit, some (like miro and matai) have their seed enclosed within a fleshy 'drupe' which is eaten whole by such birds as kereru (*Hemiphaga novaeseelandiae*).

top **Lowland podocarp–hardwood forest, here dominated by miro emergents, growing on alluvial soil near Opotiki. Opotiki District.**

bottom **The fruit of the kahikatea, near Muriwai, Auckland.**

There are 16 podocarp species in New Zealand. Some are large and typically dominate the forests in which they occur, including rimu, kahikatea, matai (*Prumnopitys taxifolia*), miro, tanekaha and totara (*Podocarpus totara* var. totara). 'True' totara hybridises with its close relative Hall's totara from the Waikato north. Smaller podocarps include yellow-silver pine, a conifer which grows in some of our upland boggy areas and reaches only 15 m. Pygmy pine (*Lepidothamnus laxifolius*), a prostrate shrub, is the world's smallest conifer; it grows in montane and subalpine scrub and moorland from Mt Hikurangi and the Herangi Range south.

Totara, matai and kahikatea prefer more fertile soils than rimu and miro, which are more prevalent on less fertile soils; matai flourishes most abundantly on fertile alluvial and volcanic ash soil. Totara is well known as a pioneer plant, often an initial coloniser of new ground and — given that it is unpalatable to stock and apt to recover when grazing pressure is light — can often be seen in regenerating bush. It doesn't like wet feet, but is drought-resistant and so in dry areas totara tends to predominate, along with matai.

PODOCARP-DOMINATED FORESTS

THE GIANT PODOCARP FORESTS OF WHIRINAKI AND PUREORA

In only a few forests are the dominant trees podocarps (softwood forests); the most abundant of these are on either side of the Central Volcanic Zone, in the Pureora and Whirinaki Forest Parks at altitudes between about 450 and 600 m, thriving in the thick volcanic soils. Only a few decades ago these forests were slated for destruction and replacement with pine plantations. In general, the most common podocarp in these forests is rimu, but miro and matai are also common, as is tawa, and one may also find totara, Hall's totara, kahikatea, hinau, rewarewa, maire and kamahi.

Pureora Forest Park and its surrounds are but a remnant of our giant totara forests, with the totara–matai–kahikatea forest that once clothed the fertile, ash-rich lowlands now covering no greater an area than that of One Tree Hill and Cornwall parks in Auckland. The totara here are the largest podocarps in the

world; they can exceed 2–3 m in diameter and live 1500 years or more; Pureora is the only forest park where all our tall podocarp species still thrive together.

On somewhat higher altitudes of the Pureora Forest Park's Hauhungaroa Range are more patches of podocarp-dominated forest. On its northeastern margin tanekaha is often common, along with the other usual podocarps (rimu, miro, matai and totara) and occasionally kamahi, hinau and maire up to about 600 m; there are also areas of small trees and poles of tanekaha, as well as pole rimu, rewarewa, kamahi and *Kunzea* species. On the southeastern side there are some valleys where matai is particularly common along with miro, totara, Hall's totara and kamahi, although rimu is only occasional; there are other areas with abundant rimu along with frequent miro, matai and kamahi and occasional totara, Hall's totara, kahikatea, hinau and maire. At higher altitudes (between about 800 and 900 m), there are areas of podocarp-dominated forest which include small miro, matai and Hall's totara, although one can also see hardwoods, including kamahi and, less frequently, maire, pokaka and broadleaf (*Griselinea littoralis*).

KAHIKATEA-DOMINATED SWAMP FORESTS

Kahikatea, the dominant podocarp of alluvial and swampy ground, is our tallest native tree, growing to more than 60 m tall. It has buttressed roots (although broad and rounded, rather than planks) which spread

top **Cathedral-like rimu trunks. Whirinaki Forest Park, Whakatane District.**

middle **The podocarps of lowland Pureora, here mainly totara and rimu. Ruapehu District.**

bottom **Regenerating totara in a paddock near Kawakawa, Far North District. A couple of kahikatea are poking their crowns above the totara in the left background, near a small stream.**

outwards to help stabilise it in the damp ground; the damper the ground, the more the buttressing. Unlike the drooping tips of rimu branches, kahikatea point upwards and are green or grey-green rather than brown-green. Other podocarps may also be present in such forests, including rimu and matai, although in lesser numbers.

The tropical-looking pukatea is also common on swampy ground. It has triangular flanges, or plank buttresses, at the base of its trunk, which help stabilise it in the wet ground and both pukatea and swamp maire, which also grows in such environments, have developed pneumatophores, specialised roots that protrude above the ground to supply the plant with oxygen in the anaerobic, waterlogged soil. The cabbage tree is another frequent inhabitant of damp places.

Vines such as kiekie, supplejack (*Ripogonum scandens*) and swamp lawyer (*Rubus australis*) are common, as is the tree fern wheki, sometimes forming groves. However, in general there is less species diversity in swamp forests than in adjacent forests on drier ground.

Kahikatea forest has perhaps been the most brutally devastated of all our forests. This graceful tree, New Zealand's tallest, once grew in great stands, particularly on the relatively wet Waikato basins and the Hauraki Plains, as well as on other alluvial plains, but precious few stands remain, given the usefulness of these landforms for modern agriculture. Some examples include Smith's Bush reserve on Auckland's North Shore, a stand behind the baches at Omaha (Omaha Taniko Scenic Reserve), a functional remnant on the margin of the Kopouatai Peat Dome bordering the Piako River, Gray's Bush in Poverty Bay — the like of which used to cover all the alluvial plain around Gisborne — and the lone trees or clumps of kahikatea (e.g. Yarndley's Bush) which are a common sight when driving through the Waikato. All are remnants of once vast forests. The largest stands of kahikatea left are in the vicinity of the Mangapu River, Te Kuiti.

left **Kahikatea swamp forest, showing the buttressed lower trunks of this swamp-adapted tree. Whirinaki Forest Park, Whakatane District.**

left **Rimu (left) and rewarewa (right) are beginning to emerge above a canopy dominated by taraire, with some puriri, on the western edge of Kirk's Bush, Papakura, Auckland.**

When such forest has been felled and allowed to regenerate naturally, it may be replaced, at least initially, by cabbage trees, New Zealand flax (*Phormium tenax*), small-leaved shrubs and small trees.

PODOCARP–HARDWOOD FORESTS NORTH OF HAMILTON

In our northern half there are areas of podocarp–hardwood forest devoid of kauri, often on lower, rolling terrain. In some instances this is because of logging or conversion to agricultural land, but there have always been some areas better suited to trees other than kauri.

Excluding some, usually alluvial, kahikatea-dominated forest remnants, rimu is usually the dominant emergent conifer. However, although podocarps often visually dominate most of our forests by virtue of their size, the number of forests where the canopy is predominantly made up by such trees is small. Usually the dominant trees by number are the hardwoods, in lowland forest predominantly taraire, while at higher altitudes towai (also known as tawhero) is often most common.

The largest areas of such forest are found in the Hunua Ranges east of Auckland and on the Coromandel; taraire is usually the dominant canopy-forming tree, up to an altitude of 450 m, and rimu and matai the most common emergents. Hall's totara and hybrids are not uncommon, particularly in the former Rodney District of Auckland and on Great Barrier Island. One also finds occasional miro and rata emergents, more commonly at higher altitudes. Other canopy-forming hardwoods include tawa, towai and kohekohe; somewhat less commonly one may find rewarewa, hinau, pukatea and puriri.

Changes at altitude

Altitudinal changes in northern podocarp forests parallel the changes seen in kauri forests; above 450 m in Northland, the Hunua Ranges and the Coromandel Peninsula, taraire

cedes dominance to tawa and matai becomes less common. Other trees that reach their altitudinal limits in these forests include puriri (see below), pukatea (550 m in the Coromandel), kohekohe (450 m in the Hunua Ranges and 550 m in the Coromandel) and mangeao (found only up to 450–500 m in the lower Waikato).

At the same time, tawari and Hall's totara become more common and, on the higher ridges of the Coromandel Peninsula, tawari can form a canopy with tawa and towai while rimu gives way to its cooler-climate relatives, miro and Hall's totara. Both tawari and towai, despite thriving at altitude, are confined to the north; towai does not grow further south than the Kauaeranga Valley in the Coromandel Peninsula and tawari is scarce south of Mt Pirongia in the west, with only sparse occurrences down to the Tawarau Forest in the Waitomo District although it is abundant in the Kaimai Mamaku Forest Park to the Horohoro Bluffs and around Te Urewera. Further south it is replaced at such altitudes by kamahi.

On the high, wet Northland plateaux

above **Inside podocarp–hardwood forest on a ridge above Cossey's Dam, Hunua Ranges, Auckland. This area of forest (and most of the higher parts of the Hunua Ranges) is dominated by rimu and tawa, but note the totara on the right; all our forests are mixtures like this, to some extent.**

below **The distinctive flat top of Table Mountain, Thames-Coromandel District; a rare tract of flat land above the steep hills of the Kauaeranga Valley. Regenerating kauri dot the foreground, along with species well suited to the Coromandel's higher ridgelines, such as yellow-silver pine, tawari and towai (tawhero).**

above 500 m, tawa cedes dominance to towai, the Northland relative of the cooler-climate kamahi. Being wet, the canopy may also include swamp maire.

Near the summit of Te Moehau are areas of forest that have a more cool-climate character, with the podocarps miro and Hall's totara and the hardwoods toatoa, including an unnamed relative of mountain toatoa (*Phyllocladus* aff. *alpinus*), towai, tawari and kaikawaka, with some southern rata and tawheowheo. As mentioned previously, however, the typically warmer-climate kauri can also be found in the vicinity.

Inland from Thames, Table Mountain, a broad, waterlogged peaty plateau at 820 m altitude, is for the north a unique environment. The main canopy-forming tree is yellow-silver pine with some tawari, silver pine and *Phyllocladus* aff. *alpinus*, as well as the occasional southern rata and manuka. However, there are also scattered kauri and small rimu. There are obvious links, therefore, to both northern lowland forests and South Island West Coast pakihi vegetation. This stunted (10 to 12 m high) tree-heath vegetation, growing on very waterlogged, infertile ground, was presumably once more common in areas that are now gumland.

PODOCARP–HARDWOOD FORESTS SOUTH OF HAMILTON: BIOGEOGRAPHICAL BOUNDARIES

From latitude 38° S, away from the coast the land rises towards the Central Plateau and the axial ranges in the east. As a result, the climate becomes cooler and wetter. In the absence of kauri, mixed podocarp–hardwood forest becomes overwhelmingly the dominant forest type. Many other endemic trees prominent further north, including taraire, kohekohe and puriri, are either absent or confined to the coast beyond this latitude; while some important southern trees, including kamahi and silver beech, either make an appearance for the first time or become more dominant, particularly at altitude. Some non-forest plants, such as mangroves, as well as some

below **Podocarp–hardwood forest near Waitomo Caves, Waitomo District. Note the large emergent kahikatea in the foreground, on the alluvial soils; rimu and tawa become more predominant on the ridge in the background.**

of the animals that depend on these forests, also disappear at around this latitude. This relatively abrupt change earned this latitude the label 'biogeographical boundary' identified as such for plants by Cockayne and for lizards by McCann, although some more-recent authors draw the line (the 'Taupo Line') at around 39° S.

Only small forest remnants survive in the low-lying Waikato basins and Bay of Plenty; these fertile lands would have been dominated by kahikatea, together with lowland totara and matai. However, on the less valuable pumice soils and lower slopes of the hill country, extensive forests dominated by rimu and tawa still survive; miro and beech also thrive on less-fertile soils, although there is much local variation. One can sometimes identify different soils, be they infertile or fertile, waterlogged or dry, by the type of vegetation present.

RIMU–HARDWOOD FORESTS

Extensive rimu-dominated forests may be found in the lower elevations of Te Urewera, the Raukumara and Whirinaki forest parks and adjoining forested areas of these axial ranges; in the Kaimai Mamaku Forest Park between the Waikato and Bay of Plenty; around Rotorua and its lakes; in the ranges that make up the Pureora Forest Park west of Lake Taupo; on the isolated, mostly volcanic summits of the Waikato; and also on the hills of our southwest, near the border with Taranaki (the Herangi Range and adjoining hill country). However, in the Gisborne District the hills have generally been stripped of their original forest cover.

Rimu–hardwood forests are characterised by a dominant hardwood canopy of tawa, tawari or kamahi with rimu emergents,

below **Rimu–tawa forest dominates the Waioeka Gorge, Opotiki District.**

above **Rimu–matai–tawa forest; the large trunks in the centre and right belong to emergent rimu but the other trunks, dominant numerically, belong to the canopy-forming tawa. Whirinaki Forest Park, Whakatane District.**

depending on the latitude and altitude; in warm-temperate-type forests, tawa predominates. Other canopy trees may include hinau and black maire (*Nestegis cunninghamii*).

The podocarps tend to be occasional emergents in a sea of light-green, the characteristic colour of tawa leaves, although the exact composition of the forest varies depending on the latitude, the altitude and how far inland the site is. Other large emergent trees include rata and miro, the latter becoming more common than it is further north and more common at higher altitudes (e.g. above 450 m in the Lower Waikato Basin). Matai is common in valley-floor forests of the hill country of both east and west, including the Paeroa Range and other small areas near Rotorua, the King Country (especially in the Hauhaungaroa and Rangitoto ranges of the Pureora Forest Park, in Whirinaki Forest Park and the southwestern part of Te Urewera). In the canopy, rewarewa and pukatea are also occasionally present almost everywhere and pokaka is also common, often in the same areas favoured by matai. Mangeao is found only in the northern half of the North Island although it is more common in the southern part of its range, in the deep composite tephra ('ash') soils of the northern King Country, western Waikato, Bay of Plenty and Rotorua area.

OTHER MORE SOUTHERLY PODOCARP–HARDWOOD FOREST TYPES

Hard beech can be found in rimu–tawa forests within a few kilometres of the coast and up to 300 m altitude, along the eastern Bay of Plenty coast; it has a warm-temperate look to it. Podocarps include the relatively northern tanekaha as well as miro and rimu. The hardwoods include rata, tawa, hinau, pukatea, kohekohe and kamahi as well as beech, in this case hard beech, the most northerly beech species. At higher altitudes (300–450 m) and further from the coast, rewarewa and tawheowheo become more prominent while the subtropical kohekohe disappears. There is also some tawa–beech and rimu–tawa–beech forest near the coast in our very southwestern corner, near Awakino.

There are some areas of forest at relatively low altitude where rimu is either sparse or absent, in the gorges of the Mamaku Plateau and in parts of the lower Waikato and King Country. Miro, thin-barked totara and tanekaha tend to be the dominant podocarps, while hardwoods include tawa and kamahi and the occasional hinau and rewarewa; tawari is present in the Mamaku Range.

PURIRI AND TARAIRE HARDWOOD FORESTS

Confined to fertile basaltic soils of our northern half, growing in hollows and gullies into which nutrients drain, these forests, which lack podocarps, have in large part been cut down and turned into farmland. Other trees present in such locations, often termed gully broadleaves, would have included mahoe, karaka (*Corynocarpus laevigatus*) and nikau, as opposed to the kauri and tanekaha of the ridges.

PURIRI

As we have seen, puriri is common in much of the lowland forest of Northland, Auckland and the Coromandel. Scattered trees form part of the canopy down each coast as far as Cape Egmont (there is a very large, old puriri in Brooklands Park, New Plymouth) and the Mahia Peninsula; its altitudinal limit in the most favourable sites is 800 m but this decreases to near sea level with increasing latitude (for instance, in the lower Waikato, its altitudinal limit is 150 m). Puriri is one of

top **Puriri in flower beneath a basalt scoria cone, December 2012, near Kaikohe, Far North District.**

bottom **The edge of a patch of puriri forest. Bombay Hills, Auckland.**

a genus of mainly tropical and subtropical trees, shrubs and herbs within the mint family (Lamiaceae) which can grow up to 20 m tall with a trunk up to 1.5 m across. Unusually for New Zealand trees, puriri has conspicuous, colourful (pink, red and, rarely, white) flowers which may be in bloom practically all year round, although they tend to come out more in winter. They mature into a bright red fruit about 2 cm across, again almost all year round although more commonly in summer. Its nectar and fruit provide an important and reliable year-round source of nourishment for native birds such as wood pigeons (*Hemiphaga novaeseelandiae*) and therefore it has been planted in places such as Tiritiri Matangi Island. Trees which have fallen on their side but which are still alive and have branches growing up vertically from the inclined trunk are also a common sight. Finally, it is also a hardwood of great strength, albeit difficult to work. It is thus often used for such items as railway sleepers, bridges, boats and piles — as long as the puriri moth (*Aenetus virescens*), New Zealand's largest moth, has not excavated it first! Epiphytes, including *Astelia*, puka (*Griselinia lucida*), tawhiri karo (*Pittosporum cornifolium*) and northern rata often perch on its branches.

The most pure puriri forests are found in the country around Ohaeawai, between Waimate North and Lake Omapere near Kaikohe, where they grow on the fertile soil among the extinct basaltic volcanic cones, although only patches remain. They also once covered the area around Pukekohe, now some of our most fertile market gardens. Taraire, rewarewa, totara, rimu, kahikatea and karaka may also be present in these forests.

TARAIRE

Taraire can occasionally form a canopy in conifer-free forest. It reaches its southern limit at Kawhia and there is also some coastal taraire present in lower-altitude, more-coastal sites near East Cape. Its close relative tawa gradually increases in prominence from mid-Northland south and eventually totally replaces it. A large tree, up to 20 m high and 1 m in trunk diameter, it has large, subtropical

left **Taraire Forest, Kirk's Bush, Papakura, Auckland.**

left **Tawa–beech forest covers hills on the right bank of the Motu River, just upstream from the road bridge, on the eastern Bay of Plenty coastline. Opotiki District.**

below **A profusion of rewarewa in the Mokorua Reserve, Whakatane District.**

leaves up to 75 mm long and produces a large, 35-mm fruit; it is highly favoured by the native wood pigeon for that reason. There is an excellent example of taraire-dominated forest at Kirk's Bush, south Auckland.

OTHER NORTHERN HARDWOOD FORESTS

In Northland and on the outskirts of the Coromandel one may also find hardwood-only patches of rewarewa, towai and *Kunzea* species, with occasional five-finger and other shrub hardwoods. A taraire–tawa forest is also found in a few pockets in Northland, Great Barrier Island and the lower Waikato, left over from podocarp–hardwood forests that have been rendered podocarp-free by either human hand or nature (often fire); the remaining hardwoods have usually also been damaged but still can form a forest. Coastal forest, described below, also tends to lack podocarps.

HARDWOOD FORESTS SOUTH OF HAMILTON

Excluding coastal forests, most patches now consisting solely of hardwoods would previously also have contained podocarps, especially rimu, which have since been felled or destroyed by natural means such as fire, gales, or landslides; the 1886 eruption of Mt Tarawera also destroyed a lot of the podocarp forest in its vicinity.

Pockets of tawa forest, similar to the taraire–tawa enclaves further north, can be

found around Rotorua and the King Country especially and there are also some localised tawa–beech forests in the vicinity of the Raukumara Range. Near East Cape there is a more coastal mixture of pohutukawa, tawa, rewarewa, kohekohe, *Kunzea* species and kowhai together with black beech (*Fuscospora solandri*) and hard beech, and on the eastern Bay of Plenty coastline are patches of pohutukawa, tawa, rewarewa, kohekohe, kamahi and hard beech forest.

There are also forest patches dominated by rewarewa, with abundant small trees, near Rotorua and in the eastern King Country, while in broken country of eastern districts there are also stands of small rewarewa and *Kunzea* species. In the western King Country there are pockets of rewarewa, kamahi and tawheowheo, with the occasional five-finger; and in the upper Tarawera Valley is an inland pohutukawa and mangeao forest with occasional tawa and rewarewa and other shrub hardwoods. Finally, from the lower Waikato and Waihi south there are pockets of rewarewa, *Kunzea* species and kamahi with occasional heketara (*Olearia rani* var. *colorata*) and other shrub hardwoods; between 800–900 m, such pockets tend to be just kamahi.

COASTAL FORESTS

The coastal forest of our warm northern bays and islands is generally a short-statured broadleaf forest without emergent conifers. Many of the common large hardwoods, such as tawa, taraire and northern rata, are also not as common by the coast as they are further inland and do not form a broad canopy. Such coastal forest gradually grades into more-typical lowland forest over a few kilometres or less, perhaps up to the first ridgeline inland from the sea.

Coastal forest has a particularly tropical look about it, with large-leaved trees and the nikau palm, as such trees are able to survive in these locations because of the sea-level, maritime climate. Our northern coasts have the most mild climate, from a temperature point of view, and in particular winter

left **Coastal forest, Little Barrier Island, Auckland. Nikau is particularly abundant in this image, along with pohutukawa.**

temperatures seldom drop to freezing. As one travels further south, some of the trees that in northern areas prosper inland start to be only found near the coast, such as puriri. However, these trees have to cope with other problems, particularly the salt-laden winds by the sea which cause damage to all elements of the forest, although some are more susceptible than others. Human interference along our coast adds to the problem. Some coastal trees, including pohutukawa, karaka, ngaio, nikau and kohekohe, have thick and glossy leaves to reduce desiccation (see also Chapter 9).

Pohutukawa is perhaps the most well-known of our coastal trees and is often a pioneering species on otherwise difficult sites such as cliffs and recent volcanic islands. Other early colonisers of exposed, harsh environments include akeake (*Dodonaea viscosae*) and, on slightly more sheltered sites, the shrubs taupata (*Coprosma repens*), coastal mahoe (*Melicytus novae-zelandiae*) and ngaio (*Myoporum laetum*) are the most tolerant of exposure. Other species that may be present in exposed sites, forming a coastal heath of stunted bush about 3–6 m high, include houpara (*Pseudopanax lessonii*), which is often dominant, other *Coprosma* species, karo (*Pittosporum crassifolium*), wharangi, koromiko (*Hebe stricta*), whau (*Entelea arborescens*), kawakawa, rangiora and five-finger; karaka often start growing in this environment but eventually can attain a height of up to 15 m.

top **Coastal forest interior, Tiritiri Matangi Island, Auckland. This forest contains abundant hardwoods, including kohekohe, *Coprosma* species, taraire and karaka as well as tree ferns; however, there are no podocarps.**

bottom **Interior of coastal forest near East Cape, Gisborne District. The trees in this patch of bush, near the bottom of the hill on the track up to the lighthouse, are typically subtropical coastal trees such as nikau, puriri, cabbage tree and kohekohe. Gisborne District.**

In areas of greater shelter and with more fertile soils, nikau and broadleaved trees predominate, forming a bush perhaps 6–12 m high. Nikau is a very typical tree of this environment and often is the dominant species; cabbage trees are also often common as they tolerate maritime conditions. Broadleaves include puriri and taraire (in the north), kohekohe and karaka as well as some large pohutukawa that may have become established earlier in the process of coastal colonisation. The understorey is often sparse, sheltered by the broadleaved cover, although lianoid plants (woody vines) such as *Muehlenbeckia complexa* may be abundant at the margins.

Perhaps one of the best examples of coastal forest close to Auckland is that on the headlands of the western part of Mahurangi Regional Park. There pohutukawa fringe the cliff areas, particularly around Te Muri and Cudlip points. Puriri, taraire, karaka and kowhai dominate this coastal forest. The understorey includes mahoe, whau, hangehange, kawakawa, various *Coprosma* species and nikau. The largest area of coastal forest extends from the cliffs back on to the adjoining hill slopes. In places, the coastal forest merges into mixed podocarp–broadleaf forest with podocarps and hardwoods which include emergent kauri, kahikatea and totara.

POHUTUKAWA

Often termed the New Zealand Christmas tree, because of when it flowers, pohutukawa is endemic to the north, down to about Taranaki and the Mahia Peninsula, although it has close cousins in the rata which grow further south, and has also been widely planted much

below **Pohutukawa dominate the coastline at Rangiwhakaea Bay, Great Barrier Island, Auckland.**

further south (e.g. St Clair Beach in Dunedin and on the Chatham Islands) — where it grows well, has become naturalised and is a pest species when it hybridises with rata outside its natural range or outcompetes the indigenous flora. The largest pohutukawa forests are those on Rangitoto and Tuhua (Mayor) islands. Near Ohope it grows much taller as a forest tree, but most of us know it as the tree that hugs the coastal cliffs, dips its feet into the salty water and provides hours of entertainment as both young and old climb and swing upon its branches. It is also present inland around the shores of Lakes Rotorua, Tarawera, Rotoiti and Taupo.

In days gone by, its timber was of value for boat construction, being unable to be penetrated by sea worms when in saltwater. Unfortunately, it is also much loved by possums and its seedlings are easily smothered by weeds and grasses.

Pohutukawa has particular adaptations that particularly suit it to its habitat; it is salt-tolerant, has leathery, drought-resistant leaves with hairy undersides to trap and retain moisture, and hanging roots which allow it to cling to almost vertical cliff sides, although the burrowing of its ever-enlarging roots in the end literally proves its downfall, acting to enhance susceptibility to erosion until the soil gives way and the pohutukawa ends up, often still alive, at the bottom of the cliff.

EPIPHYTES OF LOWLAND FORESTS

One feature of our lowland podocarp–hardwood and kauri forests is the great diversity of plants that grow on other plants, i.e. epiphytes.

Epiphytes, in the narrower sense of the word, are plants that grow high on other trees and do not reach the ground, at least in their early years. Some eventually send down roots to the soil, but before this they face a lack of soil and therefore mineral nutrients and a water-storage medium; the water-storage issue is compounded by being closer to the canopy and thus more exposed to the drying effects of sun and wind; hence, these plants have adaptations to conserve or store water. However, their location gives them greater access to sunlight for photosynthesis than if they had started out on the forest floor.

Some epiphytes can also grow directly on the ground and, under certain circumstances, any plant (even kauri) can become an epiphyte, although such plants do not reach maturity.

TREE EPIPHYTES

The first epiphytes to become established on a tree are often mosses and lichens.

Shade epiphytes, which grow low on other trees and are tolerant of low light conditions (although still avoiding the shade of large plants of the forest floor, such as ferns) include three species of strap fern (*Notogrammitis* species), three other ferns and two succulent angiosperms, both *Peperomia*, found predominantly in northern New Zealand.

The most frequently noticed epiphytes, however, are those that live in the sunny crowns of trees. Nest epiphytes are the most common; they perch on horizontal or inclined branches or at major forks, starting their life on a base of moss or lichen. All (*Collospermum hastatum*, *C. microspermum* and *Astelia solandri*) are members of the lily family. They often build up considerable depths of a spongy, dark soil as their older parts die and decay and they can contain quite significant amounts of water. They get rarer and disappear as one goes further south in New Zealand. Epiphytes that form mats (predominantly orchids and a fern, *Pyrrosia eleagnifolia*) are also present; most came

top **An epiphytic perching orchid (one of eight epiphytic orchid species), *Earina mucronata*, Lake Waikaremoana, Wairoa District. Photograph: Simon Francevic.**

bottom **Pendant and nest epiphytes on kauri. Waitakere Ranges, Auckland.**

(naturally) from Australia, except *Earina*, which may be endemic although, for now at least, there are orchids that are placed in *Earina* in New Caledonia and Samoa.

Four 'pendant' fern epiphytes may be found growing in the soil of nest epiphytes and hanging downwards; they can be seen with their roots and rhizomes in the latter's soil. Hanging clubmoss (*Lycopodium varium*) may form huge masses below asteliad nests. There are also two other *Asplenium* species of pendant epiphytes and a fork fern (*Tmesipteris elongata*); fork ferns are one of the most primitive of all land plants. We also have three orchid pendant epiphytes.

Some shrub species can also grow as epiphytes, including tawhiri karo (*Pittosporum cornifolium*) and the now threatened but once common *P. kirkii*, and kohurangi or Kirk's daisy (*Brachyglottis kirkii*); on the ground, the *Pittosporum* species can grow into much larger shrubs. Another, karamu, is perhaps best known as a ground plant in early regrowth of forest on drier sites but can be found in asteliad nests also. Larger shrubs can also grow as epiphytes, but eventually send a root to the ground to overcome their nutritional deficiencies. The best-known is puka, again more common in northern New Zealand than elsewhere; it usually starts off as a seedling in an asteliad nest, sending down roots after a few years; one becomes dominant. Broadleaf can also be observed as an epiphyte, at least initially, in more southern or higher-altitude forests and therefore usually becomes established in moss or lichen rather than asteliad nests, which are found in warmer climes.

Some trees start off as epiphytes on other trees. The most common is northern rata. Often it will start life on an emergent conifer; its vertical roots eventually enlarge to 1 m or more in diameter, often with a tripod or tetrapod arrangement of roots near the

above **A northern rata emerges above a lowland podocarp–hardwood forest; an epiphyte that becomes one of our largest trees. Maungatautari Sanctuary, Waipa District.**

ground. When the host eventually dies, the rata is capable of remaining upright and is one of our large forest trees. Sometimes such trees are termed strangling epiphytes but, although it may well compete with the host, it does not necessarily strangle it and the host may actually die of old age. In Te Paki one may also find the similarly epiphytic Bartlett's rata. Despite its name, southern rata is found throughout the north, although more frequently on Little Barrier and Great Barrier islands, the Coromandel Peninsula and the Hauturu, Warawara and Herekino ranges in Northland; it is more commonly terrestrial rather than epiphytic.

FERN EPIPHYTES

A different group of plants tends to become epiphytic on ferns as opposed to trees, given their different external substrate and lack of branches. Their large crowns also give considerable shading, especially to young epiphytes. In wetter areas, mosses, lichens, liverworts and smaller ferns are common on the trunks of larger tree ferns, and other epiphytes and plants may become established on ferns but die before maturity. Certain epiphytes, though, specialise in tree ferns.

Kanono (raurekau) and raukawa can commence life as fern epiphytes before sending down encircling roots in a similar fashion to northern rata. The hardwood tree kamahi frequently also begins life as a fern epiphyte, especially on wheki; instead of forming encircling roots, however, it sends a root vertically upwards inside the fern; eventually the fern breaks off above the

junction with the kamahi. Its northern relative towai and Northland's makamaka can also start off in a similar fashion.

Some ferns may also be epiphytic on larger ferns, including the spleenwort *Asplenium flaccidum*, the filmy ferns *Hymenophyllum* species and *Polyphlebium venosum*, the whisk fern *Psilotum nudum* and fork ferns (*Tmesipteris* species, now considered part of the fern lineage), as well as the herbaceous clubmoss *Phlegmariurus varius*. One very rare fern in New Zealand is *Abrodictyum caudatum*; fewer than 10 colonies have been found, epiphytic on wheki, at Kerikeri, although it is present on Raoul Island and in the wider Pacific and Australia.

Mountain five-finger (*Pseudopanax colensoi*), which occurs south of Northland, and raukawa are sometimes seen growing epiphytically on ferns and trees; however, this is indicative of severe goat and deer browsing in the past which has eliminated these species from more accessible sites.

GROUND EPIPHYTES

Epiphytes can also grow on the ground when there is excellent drainage and minimal competition, such as seen on the 600-year-old Rangitoto Island where a range of normally epiphytic plants, such as puka, northern rata, *Astelia solandri* and kohurangi can be found on the scoria lava. The forest there is dominated by pohutukawa which can freely hybridise with northern rata.

LEAF EPIPHYTES

Not particularly common outside of the large-leaved trees of the tropics, nevertheless small plants may grow on leaves (i.e. they are epiphyllous), including liverworts (often on ferns), algae and lichens.

VINES

Vines are those plants that start off on the ground and then grow up trees, holding on by means of special roots. This enables them to grow more quickly using resources that would otherwise be needed for structural support. Their presence is generally detrimental to their host.

SUBCANOPY VINES

Those vines that are confined to the subcanopy are, in New Zealand, all ferns. These include thread fern (*Blechnum*

left **Subcanopy vines: ferns grow on a podocarp trunk. Whirinaki Forest Park, Whakatane District.**

opposite **A woody liane swinging free in kauri forest. Waitakere Ranges, Auckland.**

filiforme) and jointed fern (*Arthropteris tenella*), both of which are most common in the upper North Island and do not reach the southern South Island. Perhaps the most common is very widespread *Microsorum pustulatum*, whose range reaches as far south as the subantarctic islands; it prefers inclined trunks and branches rather than vertical ones, so favours trees such as kamahi and fuchsia. In higher-rainfall areas one can find *Abrodictyum* species and filmy ferns in the genera *Hymenophyllum* and *Polyphlebium*. Many of these ferns can change form depending on their location — for instance, thread fern tends to have larger leaves the further it climbs up the host's trunk.

CANOPY VINES

Many vines can reach all the way up to the canopy; these are generally woody plants and are often referred to as lianes. Climbing rata, currently included in the genus *Metrosideros* and one of which, *M. albiflora,* is endemic to northern New Zealand, do not turn into large trees but live out their lives as vines. They adhere to their host by short rootlets that penetrate and cling to rough bark, allowing the plant to grow upwards, and are hence called 'root climbers'. When they reach light, the rootlets die and the plant peels away from its host with a bushy head of branches that eventually produce flowers; at this time their stem becomes thicker and swings away from the host as a woody cable. Kiekie is another root climber; it often obscures the trunks of its host tree in swampy lowland forest.

Other vines climb by twining around their host; these plants are often unable to scale very large trunks because of their tight twine — they can end up going up one small tree and then moving onto another large tree closer to the canopy. The most familiar such vine is supplejack, a type of lily; the largest diameter of trunk it has been noted to climb is 1.5 m.

Sometimes one can encounter great tangles of this plant, but it is also useful to trampers when negotiating a difficult slope. There are also two native jasmines (*Parsonsia* species) as well as two species of *Muehlenbeckia* which are twining lianas: one is *M. australis*, which can reach up to 30 m high if it climbs a very tall tree; the other is *M. complexa* which grows on shrubs or at forest margins. Other twiners include mangemange (*Lygodium articulatum*), a fern found in our northern forests, particularly kauri forests, and *Tecomanthe speciosa*, which is only found naturally (and only one plant at that) on the Three Kings Islands.

Twining leaf petiole climbers differ in that their stems are supported as they grow upwards by the stalks (petioles) of their otherwise normal leaves. All our native species are *Clematis*, the largest being the lowland *C. paniculata*. They particularly grow at forest margins.

Tendril climbers use plant organs as their supports, such as leaves that have lost their other function and are used only for climbing. There is but the one species, the native passionvine (*Passiflora tetranda*).

The final kind of vine, the hook climbers, are, in New Zealand, all *Rubus* species — a genus which includes raspberry and blackberry. They have backward-curving prickly hooks on their petioles to prevent them slipping backwards — giving them the name 'bush lawyer'; *Rubus australis*, which lives in swamps, is called the swamp lawyer.

Some species are restricted to climbing just small trees and shrubs, for instance at forest margins or in shrubland, and are known as scramblers. Others may find themselves growing with no support — often the scramblers can be found in this situation, as can *Muehlenbeckia complexa* and New Zealand jasmine (akakiore, *Parsonia capsularis*); in such situations they assume a shrub-like form with lots of thin, tangled stems.

MONTANE COOL-TEMPERATE FORESTS

In the rimu–tawa forests dominating the lowlands south of the latitude 38° S, kamahi becomes increasingly obvious with increasing altitude while less cold-tolerant species become less so. For instance, pukatea reaches its altitudinal limit between 400 and 550 m and in general is less common the further south one goes, rewarewa is not present above 550 m on the Rangitoto Range and mangeao may be found but only up to 450–500 m in the Waikato and Bay of Plenty.

On the windward side of the axial ranges, at between 450 and 850 m in the northern Te Urewera and western Raukumara ranges, the forest starts to include more cooler-climate podocarps such as miro and Hall's totara as well as the hardwoods rata, hinau, rewarewa, kamahi, tawari and tawheowheo. Beech, particularly red and silver beech, becomes common at this altitude in the axial ranges; often tawa predominate in the gullies while the various beech species dominate the ridges.

Eventually, at around 700 m, tawa is replaced as the dominant canopy-forming tree by kamahi or beech and the forest becomes either cool-temperate podocarp–hardwood forest (where beech is not present) or beech forest, or a mixture of the two.

MONTANE PODOCARP–HARDWOOD FORESTS

On the higher hills of the Waikato and Bay of Plenty, such as Mt Pirongia and the Hauhungaroa and Herangi ranges, from about 600–1000 m is a cooler, less lush forest; on the axial ranges, this would usually contain beech. Kamahi is the characteristic canopy-forming hardwood and tawheowheo is often co-dominant, particularly in the Mt Pirongia and Herangi Range cloud forests (see below). Other common species include hinau, tawari (which here is at its southern limit), rata and

left **Hall's totara (on the left) and kamahi high on Mt Pureora, Ruapehu District. A highland softwood–hardwood forest.**

the occasional tawa. In the southern South Island, this montane or cool-temperate podocarp–hardwood forest extends down to sea level.

On the beech-free Mt Pureora (1170 m) the upper limits for the more common lowland podocarps rimu and matai are 980 m and 860 m, respectively. Miro is relatively common at altitude compared with lowland forests, but reaches its altitudinal limit on Mt Pureora at 920 m. However, even below their altitudinal limits, most podocarps are only sparse at these high altitudes; above 880 m the forest is predominantly Hall's totara emergent above a kamahi canopy, Hall's totara being a characteristic podocarp of cool-climate forests (as well as, as seen before, infertile kauri soils), before giving way to subalpine shrubland near the summit.

On the neighbouring Hauhungaroa Range is a similar forest with occasional Hall's totara emergents above a kamahi canopy at around 800–1000 m; broadleaf is common with the occasional miro, maire, hinau and pokaka. On more poorly draining ground, species such as mountain toatoa, bog pine and broadleaf replace kamahi, although one may still find the occasional Hall's totara.

Similar kamahi forest can be found in a small beech-free area of the northern Raukumara Range at around 800–900 m, along with tawari and the occasional miro.

There are also a few patches of rimu–kamahi forest on the Hauhungaroa Range and on the Paeroa Range near Rotorua, above 550 m; rewarewa can also be found in the Paeroa Range. In contrast, at the northern end of the Kaimai Range, between 650 and 750 m, are areas of pink pine (*Halocarpus biformis*) and tawari with some kaikawaka and yellow-silver pine.

Smaller plants may include horopito (particularly *Pseudowintera axillaris*, which tends to be montane and is very rare in lowland forest), mountain five-finger (*Pseudopanax colensoi*), raukawa (*Raukaua edgerleyi*) and *R. simplex* (the genus *Raukaua* is shared with Tasmania and Chile),

stinkwood/hupiro (*Coprosma foetidissima*) and the tree fern *Cyathea smithii*.

Horopito tastes like hot pepper, having possibly evolved this spicy taste to make it unpalatable to moa (it certainly is to deer) and has a mimic in small toropapa (*Alseuosmia pusilla*) which may be found, mainly in montane forest, from Te Moehau and Mt Pirongia south. This looks very similar to horopito, perhaps to make it also seem unpalatable. *Alseuosmia* species are notable for their scent.

BEECH FOREST

In the north, forests dominated by beech (Nothofagaceae; the taxonomy of the southern beeches has been recently revised) are found further south and higher up where it is cooler; we therefore tend to think of beech as cool-climate trees. Only hard beech grows on mainland Northland, not forming large tracts of pure beech forest but rather intermingling with the other trees, either singly or in small groves. However, black beech is present on Little Barrier Island and beech may also be found on that northerly relic of ancient Zealandia, New Caledonia, as well as other more tropical relics of Gondwana (e.g. New Guinea). Warmer-climate beeches, including *Trisyngyne brassii*, were present in New Zealand prior to the Pleistocene.

The reasons for this relative lack of beech in the north and several so-called 'beech gaps', such as Great Barrier Island and, elsewhere in New Zealand, Mt Taranaki, central Westland and much of the Catlins and Stewart Island, are contentious.

Northland has in common with these

top **Silver and red beech reach their northern limit on Mt Te Aroha, Matamata-Piako District.**

bottom **Beech forest, Te Urewera (between Lakes Waikaremoana and Waikareiti). This forest is dominated by silver and red beech, with some black beech also present. Wairoa District.**

above **Beech forest in the interior of Te Urewera, Wairoa District. Note the relatively simple structure, with a fern groundcover, a few scattered tree ferns and small hardwood shrubs and then the canopy-forming beeches.**

beech gaps a climate that is relatively damp and humid; also, the temperature difference between summer and winter in these locations is much less than in many other parts of New Zealand and perhaps this eliminates the competitive advantage of beech over other trees. Beech would seem to have an advantage over conifer–broadleaved forests in drier parts of New Zealand. In the more southerly beech gaps the last glacial period (which began to end only around 14.5 ka) may have wiped out beech in those areas and it has not yet recolonised them.

There are also differences in the way that beech forest colonises new territory; beech usually spread slowly by contiguous growth and their seeds cannot cross saltwater — hence their difficulty in invading Stewart Island. Podocarps, on the other hand, can have their seeds widely and quickly dispersed by seed-eating birds.

In areas where beeches other than hard beech are present (the Kaimai Mamaku Range, the axial ranges and in our far southwest, on the border with Taranaki along the Mokau River), they make their presence known at altitude (for instance, in the Huiarau Range of Te Urewera) and the result is a cool-temperate beech forest. Other hardwood trees as well as podocarps are found in many of our beech forests; nevertheless, forests do tend to be dominated by either beech or podocarps and other hardwoods, and the differences between beech forests and podocarp–hardwood forests are sufficient to warrant separating them out.

Beech forest structure

Beech forest is a much simpler forest than conifer–broadleaved forest, with a much more open and less crowded aspect; in that respect, it is more akin to the temperate forests of

Europe and North America in having three layers (a canopy, an understorey and a ground layer), although the species in New Zealand are all evergreen. In the drier parts of the eastern South Island, large areas are covered in forest that contains virtually no other trees but beech. However, our northern beech forests are somewhat more diverse and tend to contain other plant species even if beech dominates. Shrubs are present, such as *Coprosma* species, as well as harsh-leaved ferns (crown fern and prickly shield fern), beech seedlings, moss, fungi and lichens.

By far the largest area of predominantly beech forest in northern New Zealand is in the axial ranges of the east, although it is also found in the Kaimai Mamaku Forest Park and in our far southwest corner. These forests are generally found above the altitudinal range of rimu, although there may be rimu emergents at lower altitudes. In the Raukumara Range and Te Urewera are red beech forests, intermixed with kamahi, tawari and tawheowheo, and red beech–silver beech forests, again with small kamahi and tawari and the occasional broadleaf. There is also predominantly silver beech forest in the Raukumara and Kaimai ranges, with shrubby tawari and, in the Raukumara Range, kamahi.

In the northern Kaimanawa Range, well below rimu's altitudinal limit, there are some areas of pole mountain beech; it is thought that these areas have developed either following fires in Maori or early European times or following natural disasters. On the same range, between 600 and 800 m, is red and silver beech forest. Mountain beech, mountain toatoa, kamahi and broadleaf are also present in other parts of the Kaimanawa Range, outside our area.

The flowering and fruiting of our beeches occurs in cycles known as 'masting', which can be predicted. These cycles occur every 3–5 years, often after warm, dry summers. Presumably masting ensures, through sheer quantity, that not all the seed produced will be eaten. Irrespectively, much of our indigenous and exotic biota is now in tune with mast years; while masting would once just have been a time of abundance for our birdlife, now it leads to boom populations of mice which in turn are predated on by stoats whose numbers increase rapidly during these events. Once beech seed and mice numbers drop to normal levels the following season, the starving stoats turn to our indigenous fauna for nourishment, usually with catastrophic results.

Beech seeds cannot usually blow much further than a few metres, meaning that areas occupied by beech forest only spread outwards slowly (which may be happening in the Raukumara Range). The young beech trees therefore usually grow up under their parents and tend to stay small until age (beech live for more than 300 years) or a natural event such as a storm removes the canopy and they can then reach up for the sky before other tree species invade into the gap.

MIXED COOL-TEMPERATE AND BEECH FORESTS

A combination of cool-temperate hardwood forest or subalpine shrub with beech forest and the occasional rimu emergent is most commonly found just above the limit of tawa on the axial ranges (the Raukumara Range and in Te Urewera), up to about 1200 m, although there are also some patches of silver beech in the podocarp–hardwood forest on the eastern side of the Hauhungaroa Range. There are also isolated occurrences of a mixed rimu–hardwood–beech forest at lower altitudes, with perhaps the occasional tawa, in our western and eastern hill country.

Mixed cool-temperate and beech forests are generally dominated by beech; such forests include rimu, other podocarps and an understorey of small hardwoods. The

left **A rimu–general hardwood–beech forest. Note the beech near the lakeside and the larger rimu on the hillside above. Southern Te Urewera (near Marauiti Hut) at 600 m above sea level; Lake Waikaremoana is in the foreground. Wairoa District.**

non-beech trees present are those typical of high-altitude non-beech forest, including kaikawaka, tawheowheo, the shrubby pink pine *Phyllocladus* aff. *alpinus* (a northern relative of mountain toatoa) and broadleaf; below about 1100 m there are also kamahi, Hall's totara and, in the eastern Bay of Plenty and Raukumara Ranges, tawari. Hard beech is the most prominent beech in the more coastal eastern Bay of Plenty forests of this type (e.g. Motu River Valley at about 800–900 m). Red beech is more common in this forest type in the lower, southwestern parts of Te Urewera, while silver beech is dominant at 1200 m on the Raukumara Range.

MONTANE CLOUD FOREST

The term 'montane cloud forest' is often given to that forest on isolated, often cloud-shrouded, moist but wooded summits such as Little Barrier Island, Te Moehau, Mt Pirongia, the Herangi Range and Mt Te Aroha; the conditions alter the forest environment significantly.

Clouds form with great frequency on such isolated heights, as moist, warm air from the sea or surrounding lowlands is forced up and therefore cooled; when air is cooled, it can no longer hold as much water which instead becomes supersaturated and visible as fog. Mount Te Aroha, for instance, has an average of 200 days of fog per year and it is very common to see all of these summits clouding over almost every afternoon even if the day starts off fine. The ground is often waterlogged, the isolated nature of the tops ensures windiness, leading to the tops of the trees being wind-shorn, and salt spray can be transported inland several kilometres. The soil is usually acidic and peat is common, given the slow rates of decomposition in the waterlogged soil. As a result of this environment the trees are smaller and shrubbier, but there is an increased stem density and the whole forest is festooned with mosses, ferns and liverworts, earning it the moniker 'goblin forest'.

Because of the persistent cloud cover, much of the precipitation occurs from

condensation of fog; the tree canopies are therefore designed to intercept moisture in the wind-blown clouds. Species present in our cloud forests include members both of the lowland forest flora and those usually found further south, including alpine toatoa, mountain cedar, Hall's totara, stinkwood, southern rata and, on the forest floor, more southern herbs and astelias, as one would expect from the altitude. Tawheowheo is characteristic, while kamahi and miro are also common. Yellow-silver pine grows on the highest summit on Great Barrier, Hirakimata/Mt Hobson, and a *Weinmannia–Quintinia–Ixerba*–southern rata combination is found on the summit ridge of Little Barrier.

above **Montane cloud forest, Mt Te Aroha, with tawheowheo *(Quintinia serrata)* prominently draped in moss and epiphytes. Matamata-Piako District.**

ABOVE THE TREELINE

Mount Hikurangi, which at 1752 m is both our highest peak and the highest non-volcanic peak in the North Island, has an abrupt treeline at around 1400 m; the only other peaks above this altitude are in the neighbouring Raukumara Range. This abruptness is characteristic of the beech forest that surrounds it, and this altitude could be said to represent the 'general treeline' in our part of the country. Above this line, the summer growing season is neither warm enough nor long enough for trees to put out new shoots, allow them to mature and become woody before frosts and dry winds arrive and destroy them. This treeline is much lower than that at similar latitudes in places with continental climates, where the summers are much warmer; for instance, the treeline on Colorado's Crestone Peak, at about the same latitude but in the middle of North America, is around 3500 m. The treeline would seem to be determined by the night-time minimum temperature, given that it is roughly equal on both northern and southern slopes and occurs approximately where, in January, the mean temperature is 10°C (the mean summer isotherm).

Just as the forest below has altitudinal zones, so are there altitudinal zones above the treeline. The lowest is the penalpine belt, that vegetation zone above the altitudinal limit of trees and shrubs over a metre high. The shrubline, the limit of erect shrubs, occurs around the 9°C mean summer isotherm; and the tussockline, the limit of extensive grassland, at around the 5°C mean summer isotherm. Above this is the low alpine belt, characterised by extensive areas of bare rock; and, when the mean January temperature drops to 0°C, the nival or high alpine belt of permanent snow and ice (New Zealand's most

northerly nival belt is on Mt Ruapehu, the summit of which, at 39°16’31” S, 175°33’48” E, lies just south of this text’s definition of northern New Zealand).

No part of northern New Zealand can be said to be truly alpine, although thanks to a degree of exposure on isolated peaks and accidents of geology, there are some tiny pockets of true alpine species in the north. The most northerly survive on some bare rock surfaces and in the most northerly cushion bog in New Zealand on Te Moehau (892 m). Isolated summits such as Mt Pureora (1165 m), which are more exposed to strong winds and orographic clouds (fog and mist) and have shallow, rocky soils, also protrude above the treeline as these factors, combined with the gradually lowering temperature at altitude, limit plant growth at lower altitudes than would normally be expected (this downwards migration of the various zones is known as compression of altitudinal zones).

above **A sharp treeline is visible on Mt Hikurangi, above which lie the penalpine and higher zones. Gisborne District.**

In general, our penalpine and alpine communities have been dispersed from those of the South Island and are therefore less diverse in comparison. The summit of Mt Hikurangi has the northernmost occurrence of many alpine species in New Zealand, including large buttercups (*Ranunculus* species), prickly wild spaniards (*Aciphylla* species) and other alpine shrubs and delicate herbs, as well as the small subalpine ‘Hikurangi tutu’ (*Coriaria pottsiana*), present on the grassy scree slope behind the tramping hut and on a few neighbouring peaks. A penalpine shrub-heath, up to

50 cm tall, is present above the treeline on Mt Hikurangi, and dominated by mountain totara (*Podocarpus nivalis*), *Dracophyllum recurvum*, *Brachyglottis bidwillii*, leatherwood (*Olearia colensoi*) and the whipcord hebe *Hebe tetragona*.

Immediately above the treeline, the subalpine scrub-shrubland on the higher Raukumara peaks, from 1370 to 1525 m, is generally dominated by leatherwood; pink pine and herbs may dominate in some areas. From 1525 to 1675 m on Mounts Hikurangi and Whanokao grows a mid-ribbed snow tussock (*Chionochloa pallens*) in alpine tussockland with species such as the bright yellow buttercup *Ranunculus insignis*, *Aciphylla colensoi* and hebes; above 1675 m on Hikurangi this changes to an alpine herbfield, dominated by buttercups and daisies (*Celmisia* species), as well as scree slopes with scattered plants. Finally, above 1701 m (and hence above the limit of extensive grassland) is an alpine fellfield with only very patchy plant cover of hardy species, which include North Island edelweiss (*Leucogenes leontopodium*), coprosmas, the grasses *Poa colensoi* and *P. novae-zealandiae*, dragon leaf, clubmosses and mountain totara.

top **Kaikawaka emergent above subalpine shrub near the summit of Mt Pirongia, Otorohanga District.**

middle **Looking down from the summit towards Lake Taupo (i.e. on the eastern side) from the summit of Mt Pureora (1170 m). Shrub-heath is visible in the foreground, blending into the darker tree-heath and finally forest lower down. In the foreground is a *Racomitrium–Coprosma–Cyathodes* shrub–mossfield; further down the dominant plants are mountain toatoa and *Coprosma* species, grading into stinkwood–mountain five-finger–haumakaroa scrub and then haumakaroa–stinkwood–broadleaf forest before transitioning into montane kamahi and Hall's totara forest. Ruapehu District.**

bottom **The subalpine tree-heath on Mt Pirongia, near the summit. Note the large mountain neinei *(Dracophyllum traversii)* characteristic of this altitudinal zone but absent on Mt Pureora. Otorohanga District.**

Some peaks in the Huiarau Range are just under the general North Island treeline height (including Manuoha at 1392 m, Mangataniwha at 1373 m, Mangapohatu at 1366 m, Te Rangaakapua at 1326 m and Whakataka at 1252 m) but poke above the treeline by virtue of how exposed they are — Manuoha by 100 m. They also have a subalpine shrubland of leatherwood shrubland, coprosmas, pink pine, stinkwood (hupiro), haumakaroa (*Raukaua simplex*) and *Gahnia procera*.

Where beech is not present, there is a relatively gradual transition rather than an abrupt treeline. The subalpine (or upper montane) zone starts at the upper limit of kamahi where the cool-temperate podocarp–hardwood forest changes more gradually, transitioning into a dense, almost impenetrable, tree-heath around 1–2 m in height comprising slow-growing ericaceous shrubs, at a somewhat lower altitude than beech forest ends. Common plants include *Dracophyllum* species, manuka, small podocarps and *Olearia* and *Brachyglottis* species. Many indigenous trees do survive at this height but are dwarfed and stunted, the warmest temperatures often being found closest to the ground. The dominant trees of podocarp–hardwood forest are not as cold-tolerant as silver or mountain beech.

For instance, on Mt Pureora (see also Fig. 1), the podocarp–hardwood bush begins to change above about 1000 m to a stunted bush 5–8 m tall, above the altitudinal limit of kamahi; this is dominated by Hall's totara, broadleaf and *Raukaua simplex* with a shrub layer including coprosmas and epiphytes, such as the fern *Hymenophyllum multifidum* and bryophytes, reflecting the moist, foggy atmosphere common to this peak. About 30 m below the summit, although at a lower altitude (1020 m) on the more exposed western side, this bush ends in a shrub-heath 0.6–1 m tall, with bog pine (*Halocarpus bidwillii*), mountain pine (*Phyllocladus alpinus*), broadleaf, *Raukaua simplex*, *Coprosma* and *Olearia* species and *Hebe stricta*, as well as some very stunted Hall's totara less than 1.5 m tall. The turf on more exposed rises, under bog pine and *Olearia arborescens*, includes such species as bog mingimingi (*Cyathodes empetrifolia*), mountain oat grass (*Deyeuxia avenoides*), the sedge *Oreobolus pectinatus*, woolly moss (*Racomitrium lanuginosum*) and the moss *Dicranoloma robustum*. It is notable that the recent tephra that makes up the soil here is capable of supporting species of deep Recent Soils, such as *H. stricta* and *Astelia fragrans,* in close proximity to shallow gley podzol vegetation such as bog pine and *Oreobolus pectinatus*. The summit itself has been disturbed by the building of a trig station and there is a thin, discontinuous layer of turf and some andesitic boulders. There are some notable absences, such as that of red tussock (*Chionochloa rubra*), *Dracophyllum* species and, lower down, tawari and the conifers kaikawaka, silver and pink pine, probably a lingering effect of the Taupo eruption as all are present in similar climes and many are found in reasonably close proximity to Mt Pureora; the absence of beech may also be for this reason.

An interesting observation is that most of our alpine and subalpine flora must have evolved from more-lowland species, given that we are a long way from any other landmass with similar altitudes and temperatures and that our mountains are relatively young. It is commonly thought that many genera, such as *Coprosma*, *Pittosporum* and *Myrsine*, are so diverse and occupy such a variety of different habitats because they underwent 'adaptive radiation' where some species evolved into many different forms to suit more alpine climes, increasing the diversity within each genus.

PARASITES AND HEMIPARASITES

Some plants parasitise other plants, having root-like organs to penetrate their host and derive nourishment; some receive so much nourishment from their host that they have lost their own chlorophyll. Many are much rarer now than they once were and some have even become extinct. Our only native fully parasitic flowering plant of this type is the dactylanthus (*Dactylanthus taylorii*), which emerges as a flower without green leaves and sends out a root-like appendage that searches for other trees such as *Pseudopanax* and *Pittosporum*. On finding them, it penetrates their tissues and directly parasitises the host's food and water. It is pollinated by the native short-tailed bat but is now very rare and eaten by rats and possums.

Hemiparasites, such as the mistletoes (families Loranthaceae and Viscaceae), do produce their own green leaves and hence their own food, perching in a canopy tree to gather in light while draining minerals and water out of their host's xylem via suckers. *Ileostylus micranthus* was (and in some places still is) the most common and wide-ranging parasite; in dense forest it colonises canopy branches of species such as totara, hinau and tawa — so you don't tend to see it. Next most common is *Tupeia antarctica*, a monotypic genus (i.e. this plant is the sole species of a genus, and in this case endemic to New Zealand), which often attacks *Pseudopanax*, *Carpodetus* and *Pittosporum* as well as introduced shrubs and trees and even *Ileostylus*.

One hemiparasite, maire taiki (*Mida salicifolia*), can grow into a tree 6 m tall. It draws nourishment, particularly water and nutrients, underground from the roots of kauri, rimu and tanekaha although it has its own chlorophyll; it is most commonly found in kauri forest but in some areas it has become almost extinct due to browsing of possums, deer and goats. It is most abundant on possum-free offshore islands.

In Northland, red mistletoe (*Peraxilla tetrapetala*) has been found as far north as the Whangaroa Harbour, parasitising pohutukawa and puriri; it is still known locally around Waipoua on towai and is very common near the summit of Little Barrier Island, where it attacks tawheowheo and towai, species which were once also the preferred hosts for it on the Coromandel Peninsula. On Mt Te Aroha, *Peraxilla colensoi* occurs on silver beech. The now extinct Adam's mistletoe (*Trilepidea adamsii*) was once endemic to the upper North Island, ranging from near Paeroa and Maungakawa up to Waipoua and including Great Barrier and Waiheke islands; it was mostly found along streams and in coastal forest on mapou, mamangi and wharangi; *Muellerina celastroides*, a shrub hemiparasite also present in eastern Australia, used to be found in the Bay of Islands.

The most common hemiparasites in beech forest are (or at least were, before the possum invasion) the mistletoes *Alepis flavida* and both *Peraxilla colensoi* and *P. tetrapetala*. There are old records of *Alepis* from near Thames, perhaps on hard beech.

We also have two Lauraceae species, *Cassytha paniculata* and *C. pubescens*, in Northland (though naturalised around Auckland); these twining vines are also found in Australia.

ORCHIDS AND VASCULAR SAPROPHYTES

New Zealand has 35 genera of orchids with more than 160 species, including greenhood, sun, spider, caladenia, potato, perching, beard, bird, onion, gnat, leek and other orchids, although often each genus is represented only by one or two species; their ancestors were blown across from Australia. Orchids are one of the largest families of flowering plants, using insects to pollinate each other; many overseas orchids lure a specific insect pollinator by mimicking other plants, using smells or even appearing to be the female of the target insect species. However, New Zealand's orchids are unusual because they are so small and nondescript. It is probable that because our invertebrate fauna is a relatively depauperate and generalist one, orchids have to be similarly non-selective — those that arrive here needing a specific pollinator that is not also here are doomed. Further, orchids produce large numbers of tiny seeds that cannot germinate until they are infected by a soil fungus that provides nutrients and usually then stays with them throughout life, so the fungus (endomycorrhizas typically of phylum Basidiomycota) is also required to be present.

Many orchids grow only in successional, changing habitats rather than climax vegetation (like a lot of our threatened plants) — meaning that restoring ecosystems to their 'pristine' climax state might actually threaten orchid survival.

We have already met epiphytic orchids, of which we have eight, such as peka-a-waka or bamboo orchid (*Earina mucronata*). Other orchids are saprophytic, i.e. they live in the leaf litter of rainforests, feeding on decaying plant material; indeed, all our vascular saprophytes are orchids with the exception of *Thismia rodwayi*, a close relative of the orchids found only in the North Island as far south as Tongariro, although also in Tasmania. Saprophytic orchids are pale-coloured with white flowers because they lack chlorophyll and cannot synthesise their own food; they therefore depend wholly on their fungus partner to derive organic nutrients from nearby tree roots. Species include the potato orchids (*Gastrodia*), the hidden spider orchid (*Molloybas cryptanthus*) of manuka and beech forest, and *Danhatchia australis*, which can stay below ground for years if conditions are unfavourable; found always at the base of taraire and nikau trees, it is actually tied to the latter.

right **An orchid, *Pterostylis agathicola* or kauri greenhood. Usually found in kauri forest. Auckland. Photograph: Simon Franicevic.**

THE SMALL PLANTS OF THE FOREST FLOOR

As one walks along through the forest, one is often treading on a seamless carpet of liverworts, mosses and hornworts (collectively known as bryophytes), especially in moister areas such as around Lake Waikaremoana. These more-primitive plants lack the xylem and phloem transport tubes for water and nutrients and, as a result, cannot grow as large as vascular plants can.

Bryophytes living on slightly uneven forest floors can survive the leaf-litter rain of most New Zealand forests because the leaves are generally small, although in northern New Zealand there are some larger-leaved species and in such forests bryophytes only occur where leaf litter cannot accumulate, such as on sloping sites or near streams. The lowland bryophytes, living in a moister environment, tend to be different from those in the upper montane environment where the canopy is lower, light levels are higher and there is more exposure to drying winds. Dry-tolerant epiphytic mosses tend to predominate in the high canopy and there is a distinctive twig flora, especially on lowland forest margins, with *Coprosma* having the richest such flora.

New Zealand is fortunate to have a spectacular diversity of liverworts, between 600 and 1000 taxa; more than 300 are endemic and 12 are nationally endangered. This represents 5–10% of the world's liverwort species and includes members from 40% of the world's genera; of the 18 endemic genera, 16 are monotypic (i.e. with only one species in the genus). Some, such as *Monoclea forsteri*, can be quite large, while others, like the many species of *Lepidozia* and *Telaranea*, are minute with stems one-third of a millimetre across.

The majority of terrestrial liverworts grow in places such as cliff and boulder faces, overhangs, streambanks and road cuttings, as these are well-lit, free of leaf litter and often receive either direct rainfall or seepage

top left **Sphagnum moss carpets the ground underneath the vascular plants. Te Urewera, Wairoa District.**

top right **The moss *Dawsonia superba*, which can grow up to 50 cm tall, on the forest floor. Maungatautari Scenic Reserve, Waipa District.**

from above. Soil and humus at the base of trees tends to be free of leaf litter but usually the light is poor and moisture can be a problem; *Zoopsis* is perhaps best adapted to this niche. Other members of Lepidoziaceae and Lophocoleaceae grow epiphytically up the sides of trees. Some liverworts are even epiphyllous (i.e. they grow on or are attached to the leaves of other plants), mainly in very moist environments such as on low-level ferns and leaves close to streams. In general, liverworts are able to tolerate a wider variety of climates than many other plants. However, some are confined to the area north of a line joining Kawhia to East Cape, just like many trees, and others to just the North Island, the upper South and lowland Westland.

One can consider mosses in New Zealand in three categories — sphagnum, other forest mosses and granite mosses. Granite mosses, which grow mostly on rocks with a high silica content, are not common in forests. Sphagnum mosses are the stuff of heathland, forest peats, and peat bogs; their high acidity acts as an antiseptic, inhibiting bacteria and fungi that normally break down vegetative material, and they are highly absorbent of water. Our forest mosses tend to prefer moist conditions (with exceptions such as those in the Fissidentaceae and Pottiaceae families) but are as water-loving as sphagnum moss. Forest mosses often grow on bare surfaces such as rocks, bark and rotting wood; clay banks and the bases of tree trunks are rich in nutrients and are often thickly covered in moss.

Hornworts are separate again. Superficially they often look like liverworts, but ultrastucturally they are very different; many now believe they are more closely related to green algae.

FUNGI

Commonly found in our forests, fungi form a separate kingdom in the tree of life from both animals and plants, sharing some features with each but also containing some unique features. For instance, their cell walls include chitin, which is also produced by many animals (chitin is the main component in the exoskeleton of arthropods), but while plants and fungi both have cell walls, animals do not. It is thought that fungi diverged from animals and plants perhaps around one billion years ago but are probably closer to animals than to plants, despite their more plant-like appearance. None have chloroplasts and, as a result, they are unable to photosynthesise their own organic molecules. Hence, like animals, they derive nutrition from other organisms, both living and dead.

The vast majority of fungi grow as multicellular thin strands called hyphae to form a branching and intertwining network, known as a mycelium, throughout the substrate in which each lives. They may have large, visible fruiting structures, such as mushrooms, which is the only part one usually sees. These fruiting structures are used for sexual reproduction (although fungi can also reproduce asexually). Truffles (in the broader sense) are those macroscopic fungi that fruit underground, of which we have 100–125 species. When the hyphae become macroscopically visible on objects,

top **An earthstar fungus — the 'petals' of such fungi curl up when dry and the whole organism may detach from the ground and roll around like a tumbleweed! Chatswood, Auckland. Photograph: Simon Francicevic.**

bottom **Lichens encrust a coastal rock. Peach Cove, Whangarei District.**

for instance when they become visible as discoloured patches on foods, we term them 'moulds', although not all moulds are fungi (e.g. slime moulds). About 1% of fungi are yeasts, which exist as unicellular spores.

Fungi vastly outnumber vascular plants, such that for each species of the latter there are estimated to be six different fungal species. Approximately 50% of our non-lichenised fungi are endemic and 30% are exotic; so far, we have catalogued 8400 species but there remains an enormous number as yet unclassified.

The most prominent fungal phyla are:

- Ascomycota: the sac fungi. The largest phylum (5300 species in New Zealand), their sexual spores are produced in sac-like 'asci', hence the name. They include morels, some mushrooms, truffles and filamentous fungi. Most lichenised fungi and yeasts are Ascomycota.

- Basidiomycota produce their spores on club-like basidia. There are approximately 2800 New Zealand species. Most mushrooms are from this phylum, as are rust and most smut fungi, which are important cereal pathogens.

Landcare Research maintains an online database of our fungi, called 'NZFungi'. It is very hard for the non-specialist to identify fungal species and often one will see fungi described according to their structure; as a result, some fungi whose structures appear similar may be placed in the same 'form group' but may not be closely related. However, the nomenclature of fungi has recently been revised so that each fungus only has one scientific name.

Around 20% of fungal species are lichenised; that is, they usually exist in a symbiotic (mutually beneficial) relationship with a photosynthetic organism, either a cyanobacterium or an alga. Lichens are particularly important as first colonisers of barren rock and can become established in almost any terrestrial habitat — even inside rocks in Antarctica — although they are sensitive to pollution. As a result of this symbiosis, the fungus has its own food supply and, in return, provides a secure, sheltered environment for the alga and facilitates gas exchange.

Other important functions of fungi, without which life as we know it would not exist, include the following.

- One of the reasons why plants have so successfully colonised the land is a symbiotic association with mycorrhizal fungi, which are present on the roots of most plants. Their

top **Mushrooms growing on dead wood. Chatswood, Auckland. Photograph: Simon Francevic.**

bottom **A giant is being killed by a microbe in the Trounson Kauri Park, Kaipara District. Kauri dieback is currently a significant risk to our kauri forests, spread, perhaps ironically, by those of us who enjoy them most, as it is caused by a fungus-like pathogen, *Phytophthora* 'taxon Agathis' (PTA) which is carried from tree to tree and forest to forest on the dirty boots of trampers as well as on animals such as dogs and pigs. Recent trail closures in Auckland's Waitakere Ranges are an attempt to halt the spread of this devastating disease.**

hyphae enable the plant to extract more nutrients from the soil. Members of the phylum Glomeromycota form 'arbuscular mycorrhizas', where the fungal hyphae invaginate the plant cell membrane to increase the area of surface contact between the two. This, the most common type of relationship, is present in the vast majority of vascular plants. Beech, manuka and members of the kanuka group form ectomycorrhizal associations, mainly with Basidiomycota, where the root is encased in a mantle of fungal hyphae which also penetrate between the outer cortical cells. Some ectomycorrhizal networks allow exchanges between plants of different species. Introduced mycorrhizal fungi seem to be taking over from natives in our beech forests — to what eventual effect we do not yet know.

- Some fungi appear to exist inside plants without causing disease (endophytic fungi).

- Other fungi are plant pathogens; the white rot disease of Monterey pine is caused by *Amylostereum areolatum*, using insects as a vector. Native plants and fungi have grown up together, so although there are many parasitic relationships these are usually in state of biological balance. There are not many native pathogens of introduced plants, although two species of *Armillaria* can attack pine seedlings and cause root rot; most pathogens of introduced plants (such as cereals) are themselves introduced, often in conjunction with their host species — usually inadvertently, of course, if they are pathogens with economic costs! Some introduced plant pathogens can help control unwanted plant species; the smut fungus *Entyloma ageratinae* was deliberately introduced for the biological control of the weed mistflower (*Ageratina riparia*).

- Fungi are also very important in the breakdown of dead organic matter and provide food for

many animals; they are usually the first to invade dead plant material, softening the leaves and woods enough for it to be chewed up by small animals in the leaf litter; microbes then continue to break down the material excreted by these animals. This process is termed rot; in brown rot, the lignin remains mostly intact, but in white rot, the lignin is broken down to leave the whiter cellulose — which some fungi can also break down further. There is also an intermediate 'soft rot'.

- Fungi can degrade harmful substances such as herbicides and pesticides.

- Fungi are also themselves recycled into the food chain, becoming food for various species, ranging from some of our relatively primitive moths to humans.

- Since lichenised fungi can grow almost anywhere, including on bare rock, they are frequently the very first soil-forming organism in a new territory.

- Some fungi produce pharmacologically active products; some toxic, some hallucinogenic (e.g. magic mushrooms *Psilocybe subaeruginosa*) and some medically useful — e.g. penicillins.

- Fungi may also compete with and parasitise animal species, which may be economically useful if the species they affect, such as bacteria, insects and other invertebrates, are harmful; on the other hand, they can also affect human health. Many are quite host-specific. The first ever fungus to be described in New Zealand was *Cordyceps robertsii*, which parasitises Hepialidae (including porina moth) caterpillars. Eventually the caterpillar dies, leaving a mummified body behind (a vegetable caterpillar). A few predate small soil animals such as nematodes, for instance by using ingested spores or toxins.

below **Note the brown sooty mould covering the manuka trunks in this photo. Near Lake Wainamu, Auckland.**

- Some fungi also compete with micro-organisms and other fungi for space and nutrition and can be biological controls for those species.
- Some fungi live in mammalian dung, having passed through the digestive system and come out the other end intact.
- Sooty moulds are fungi which utilise honeydew secreted from insects such as aphids and scale insects as well as other plant exudates; their growth coats the plants with a sooty black colour and the result is a complex and interrelated community of plants, insects and fungi feeding on and parasitising each other.

Finally, although most fungi are terrestrial, they are also common in freshwater and a few are marine. Chytridiomycota fungi are thought to play a role in controlling phytoplankton populations, and the chytrid fungus *Batrachochytrium dendrobatidis* appears to have caused global declines in amphibian populations; this fungus has been found in the endemic Archey's frog (*Leiopelma archeyi*; classed as Nationally Vulnerable) in the Coromandel, where it is in decline, but not in other populations (as yet).

FOREST FAUNA

A formal overview of the terrestrial animals of northern New Zealand is provided in Chapter 7. However, a short overview of how this fauna interacts with our various forest types is required here.

Most animals, particularly the natives, are forest-dwellers, given the predominance of this environment in the north before humans invaded. Not only that, but those animals which spend some part of their lifecycle in freshwater, such as mayflies, are often also found in forests, given the number of streams, pools and wetlands that dot this environment. Such animals are an important part of the forest ecosystem.

The fauna interacts with the plants on many different levels; the greatest diversity of animals is found on the forest floor, where animals, particularly insects and (deeper down in the soil) worms as well as micro-organisms and other species, break down and recycle dead wood in combination with fungi. In general, the larger the animal, the bigger the pieces of debris it breaks down, leaving smaller pieces for its smaller cousins. Some animals, such as the true bugs (order Hemiptera), suck the juices of living plants; and fungi, which are more closely related to animals than plants, are the most common plant pathogen. Other invertebrates, such as weta, aphids and stick insects, are herbivorous, feeding directly on plant leaves and other soft tissues while others feed on fungi; we have a higher proportion than much of the rest of the world of moths that feed on fungi and lower plants. Some animals are very particular in which plant they eat; the caterpillars of the magpie moth (*Nyctemera annulata*), feed on rangiora and *Brachyglottis hectorii* alone of all native plants, although they have also diversified to feed on several herbaceous introductions such as ragwort.

In turn, small animals serve as prey for

left **Wood pigeon (kereru), Auckland Zoo, Auckland.**

larger animals, including larger invertebrates such as beetles and mantises as well as vertebrates, including lizards and insectivorous birds, forming a complete ecosystem which, since the removal of many native species, has broken down to a greater or lesser degree.

Some animals, for instance the nectar-feeding birds such as the tui, bypass this multi-level food chain and feed directly on plants. The benefit is not all one-way, as the plant may also derive a benefit from being fed on by animals; particularly in a podocarp–hardwood forest, animals of all descriptions aid in pollination and seed dispersal. Small invertebrates, such as flies, bees and moths, are important in pollination while larger species such as lizards and birds tend rather to transport seeds, either by ingesting them and then excreting them somewhere else or by allowing 'sticky' seeds such as biddy-biddy (piripiri, *Acaena* species) to hitch a ride on their feathers. Those plants with the largest seeds, such as taraire and miro, are almost completely reliant on the largest extant bird for seed transportation, the kereru or native wood pigeon, given the extinction of other large herbivores.

Kakapo (*Strigops habroptilus*), now extinct over most of its natural range, aligns its breeding to the mass seeding (masting) of rimu and, to a lesser extent, pine and yellow pine and other podocarp species.

It is likely that before the coming of man and his predators, many seabirds now confined mainly to offshore islands were much more common on the mainland coast and even inland and played an important role in the forest ecosystem, in particular by adding their fertiliser to the soil; some also shared burrows with tuatara. We know, for instance, that the black or Parkinson's petrel (*Procellaria parkinsoni*) used to breed on the mainland North Island (as well as near Nelson in the South Island). Hence, to promote forest and ecosystem restoration, various groups are trying to restore seabird colonies; for instance, at Tawharanui they are trying to protect and grow the colonies of grey-faced and diving petrels.

KAURI FOREST FAUNA

A diverse fauna also used to inhabit kauri forest, including the Northland tusked weta (*Anisoura nicobarica*), weka (*Gallirallus australis*), morepork (*Ninox novaeseelandiae*), bellbird (korimako, *Anthornis melanura*), tui,

fantail (*Rhipidura fuliginosa*), tomtit (piropiro, *Petroica macrocephala*), North Island robin (toutouwai, *Petroica longipes*), riroriro/grey warbler (*Gerygone igata*), popokatea/whitehead (popokatea, *Mohoua albicilla*), kaka (*Nestor meridionalis*), North Island bush wren (*Xenicus longipes stokesii*), rifleman (titipounamu, *Acanthisitta chloris*) and North Island saddleback (tieke, *Philesturnus rufusater*), although because of predation many of these are no longer present in many of our forests. A vast multitude of bugs — centipedes, stick insects, flies, crickets, kauri snails — also inhabit the forest, providing food for much of the birdlife, and the short-tailed bat roosts in the hollow trunks of large old trees. Finally, reptiles, including tuatara, bush skinks and green geckos, all used to be common within our kauri forests.

During its life, kauri has an impressive immune system, but in the end it is often fungal heart rot, caused by species such as *Elfvingia applanata*, *E. mastopora* and *Trametes versicolor*, that causes the final decline of older trees. Other serious disease-causing organisms (pathogens) include *Phytophthora cinnamoni*, which lives in the soil and attacks kauri rootlets, and *P. hevea*, causing canker and root rot. A mushroom, *Armillaria novaezelandiae,* can also cause root rot but is rarely lethal. More recently, *Phytophthora* 'taxon Agathis' (PTA) has been discovered in several of the North Auckland Peninsula's kauri forests, including the Waipoua Forest, the Waitakere Ranges and Great Barrier Island, and has recently been reported in the Coromandel. It is spread on trampers' dirty shoes (making cleaning of shoes and boots both before and after exploring kauri forests essential and leading to the closure of some tracks) as well as through soil transportation via other means, root-to-root contact and via groundwater. It attacks kauri roots, preventing adequate transport of nutrients.

In the foliage, the fungus *Vizella tunicata* as well as leaf-roller caterpillars, weevils, beetles and the kauri leafminer also are able to graze on the canopy.

When the kauri finally falls, dies and is broken down, the increased fertility may provides a chance for hardwood trees such as tawa, taraire and towai to claim the space. However, if they don't, manuka grows up and kauri seedlings grow up in the manuka's sheltering care.

BEECH FOREST FAUNA

Compared with conifer–hardwood forest, there is relative lack of fruit and nectar in beech forest and hence birds such as tui, bellbird and wood pigeon are less common. However, perhaps by way of compensation, there are a lot of insects that feed on the beech, associated animals, plants and fungi and the relatively more abundant leaf litter; wherever there are insects, there are also insectivorous birds. North Island robins also forage in the leaf litter and tomtits in the understorey, while kaka strip bark from trees to uncover grubs. Riflemen pick insects from cracks and bark while fantails eat on the fly. Up high in the canopy the grey warbler feeds; at night, when all others are asleep, out comes the brown kiwi (*Apteryx australis*) to search for insects below the leaf litter in the soil. The brown creeper (*Mohoua novaeseelandiae*) is confined to the South Island.

The beech canopy also tends to support a richer leaf-eating fauna than either kauri or podocarp–hardwood forests. However, most of the leaf-eaters in any canopy are weta, caterpillars, stick insects and grasshoppers and they are often very well suited to that environment — for instance, one particular caterpillar can curl up to mimic a beech leaf.

THE DYNAMIC FOREST

Forests are dynamic, not fixed; and what grows where is not simply a product of what is most suited for the current climate, soil and other environmental factors. New Zealand is a very dynamic environment geologically and, over time, climatically. This has dramatically affected the vegetation types we see today, and continues to do so.

Important concepts when discussing forests are the terms 'succession' and 'climax'. Succession refers to the way in which vegetation of one type gradually gives way to that of another; climax vegetation is that type of vegetation present when the forest reaches a steady state — which of course is never truly the case. We use the term 'primary succession' to refer to vegetation that becomes established on raw mineral soils, such as that growing on Rangitoto Island, whereas 'secondary succession' refers to vegetation established on soil developed by previous vegetation, which has been cleared by some agent, such as fire or human hand.

Local reasons why forest composition may change can generally be divided into two groups.

- Cataclysmic events that destroy all the forest. The first generation of trees will be those that are best able to pioneer new areas — surviving in exposed conditions, with plenty of light but often subject to drought and more extremes of climate; kauri are probably better at this than some other hardwood trees.
- Senescence, as large forest trees gradually age and die. The seedlings of trees other than those of the original dominant trees may survive better under the remaining canopy. For example, the seedlings of hardwood trees may survive better under a dark, closed hardwood canopy with kauri emergents than those of kauri, and the kauri will then not be replaced by their own kind as they die.

Generally, when an agent such as fire removes the forest, bracken fern is the first to invade, followed by manuka and *Kunzea* species, both small-leaved, light-demanding species. Other broadleaved plants that may invade include five-finger, lancewood, karamu, kohuhu (*Pittosporum tenuifolium*), rewarewa, kamahi and, in moister places, tree ferns (e.g. mamaku and ponga), mahoe (*Melicytus ramiflorus*), wineberry, tree fuchsia and pate.

Eventually these broadleaved trees overtop the *Kunzea* species and manuka, causing the latter to die off, and at about 50 years — assuming that there is a sufficiently large canopy gap to allow a reasonable amount of light down to the forest floor but still retaining good shelter — podocarps become established, especially totara and matai. Underneath the pole-stage podocarps the lower layer becomes dominated by kamahi, often growing on ponga, with rewarewa, hinau and maire present and rimu and miro becoming more dominant. With increasing shade, in the majority of the North Island tawa then takes over from kamahi and northern rata is also found as an emergent. Tawa and other trees that are shade-tolerant can replace themselves indefinitely. The stages that the forest goes through on the way to becoming climax forest are known as 'seral' stages.

However, conifers have some

above **Bracken (foreground), manuka (background) and tree ferns (middle distance) invade the previously ravaged Torehape Scenic Reserve. Hauraki District.**

disadvantages when compared with broadleaved angiosperms, including less efficient vascular transport and poorly vascularised, sclerophyllous (i.e. hard leaves with short distances between each one) and thin leaves that limit their growth rate, particularly when young. As mentioned, therefore, with time there would appear to be a trend for hardwoods to replace conifer-dominated forest, especially if conditions remain stable and the canopy relatively closed, with only the occasional tree fall not creating a large enough light gap in the canopy for conifers to take advantage of the conditions before the hardwoods lock them out.

The question therefore arises as to how conifers remain as a feature in our forests under such conditions. The answer may lie in the great longevity of individual trees, in the order of 1000 years or more, vs 250 years for beech, coupled with the frequency of catastrophic disturbance in our forests; if trees live long enough, then they stay around long enough to take advantage of such catastrophic disturbances. Large disturbances, for instance caused by volcanic eruptions or ex-tropical cyclones (and, most recently, the actions of humans), are capable of destroying everything for miles around, which would allow podocarps to recolonise the whole area; this seems to have happened in Pureora Forest Park, where podocarp forest has succeeded hardwood forest after an eruption and now may be on its third or forth generation. In Whirinaki Forest Park it would also appear that one type of podocarp succeeded another over time following the devastation wrought by a Taupo eruption; the pioneering totara would have dominated initially but then was overtaken, in turn, by matai, rimu and miro. Indeed, much of our podocarp forest, which predominates south of about Hamilton, where kauri stops, dates from after the destruction caused by the last Taupo eruption. Although this was almost 2000 years ago, given the length of time trees live for, these forests may still not be climax vegetation. Other species which cannot disperse quickly, such as land

left **Kauri and rimu forest gradually reclaiming the slopes of Table Mountain following logging. Kauaeranga Valley, Thames-Coromandel District.**

snails, have also been affected by these eruptions and are often missing or infrequent in this area.

Conifers also do have other advantages. Eventually they achieve a massive size, larger than the vast majority of angiosperms, and hence maintain their position in the sun. Their leaves are much more long-lived and resistant to damage than those of hardwood trees, especially those with very broad leaves; this characteristic may be helpful in harsh environments such as on drought-prone land or in nutrient-poor or waterlogged soils. An advantage in cold climates is also a characteristic of such leaves, although compared with those of the Northern Hemisphere, Southern Hemisphere conifers are not as cold-tolerant, probably as a result of the more oceanic climate in the higher latitudes of our hemisphere (except, of course in Antarctica, where conifers did once exist but have completely died out, because of the extremely harsh climate there). Hence, introduced pines are often able to thrive above the climatic limits of our own conifers as wilding pines, a particular problem in more southern parts of New Zealand.

Kauri forest shows a similar pattern of regrowth, common now in many parts on land that was cleared in early European times, with the pioneering manuka and *Kunzea* species being overtopped by the tall and narrow juvenile kauri rickers.

However, kauri seedlings in particular would seem to have difficulty establishing under their parents, in the impoverished soil, although, on many sites in Northland there would appear to have been several generations of kauri forest. At least two possibilities exist for this occurrence.

- Catastrophic events have already been mentioned as a mechanism by which conifers may establish in preference to hardwoods. There is evidence that there could have been a tremendous ex-tropical cyclone that destroyed a lot of forest several centuries ago; kauri may have been able to spread into gaps formed by such an event and still be living there now, as kauri is a relatively early pioneer species but

very long-lived. If conditions were to remain stable, kauri might not sustain its population everywhere that it exists now.

- Another source of kauri regeneration might be the way in which, in the act of falling over, giant kauri roots break up the ironpan that they themselves have produced in the soil, allowing seedlings to flourish.

Nevertheless, in time it might be that hardwoods end up dominating, especially away from the relatively infertile and sunny ridges where kauri would seem to have an advantage.

Of course we may never know what our true climax vegetation is, New Zealand's geography being so subject to change. Ex-tropical cyclones, perhaps of smaller intensity than the Northland one, quite regularly make landfall in northern New Zealand and leave devastation such as landslides and fallen trees in their wake. Volcanic eruptions and earthquakes are similarly not infrequent, especially on a scale measured in generations of podocarps. Furthermore, podocarps have co-existed with hardwoods for 100 million years so neither are likely to become extinct any time soon, at least in the absence of human intervention.

Forest can recover quite quickly from the effects of a volcanic eruption; the Tarawera eruption of 1886 is instructive in this regard. Most of the district was covered in shrubland and fernland prior to the eruption, although tall podocarp forest was present on the flanks. This forest was totally destroyed by hot ash and debris. Falling mud stripped trees of branches and destroyed low-lying vegetation for miles around, although within a few months these were sprouting new leaves. Four years later, many smaller trees were recovering vigorously and scrub and bracken formed a carpet on the ground. On the flanks

below **A giant falls — an uprooted kauri. Waitakere Ranges, Auckland.**

of the volcano, 14 years later there was little regrowth but 30 years later pohutukawa, rewarewa, kamahi and shrubs blanketed the lower flanks in places. Nowadays, forest has reclothed the flanks and shrubland is spreading upwards, often dominated by tutu. Even on the summit, where the regrowth has been slowest, taller shrubland is emerging.

The Taupo eruption of 1.8 ka covered a circular area in 20 km^3 of pumice and ash, coating some 30,000 km^2 in more than 10 cm of debris, and the accompanying pyroclastic flow covered 20,000 km^2 in thick ignimbrite, the product of hot gas, pumice and rock that destroyed everything in its path. Fires also would have been ignited further out, and toxic chemicals may have also killed vulnerable plants.

Probably, however, as close to the vent as 20 km some forest remnants survived, perhaps trunks which could resprout, and further out, isolated trees would have survived. Bracken, scrub, herbs and tutu probably resurfaced the pumice within a few years. These shrubs made fruits which attracted birds, bringing with them the seeds of podocarps, especially matai and totara, at the expense of rimu, beech and hardwoods that had previously dominated the less fertile and more poorly drained soils, as compared with fresh pumice. Thus by 300 years later, tall forest again dominated the landscape, although with a different composition.

The most dramatic environmental change, however, must be the advent of humans with widespread clearance of native forest. This began with Maori and continued with European colonisation. Europeans also brought with them large numbers of exotic plants which compete with the natives. Our fauna has also changed; for instance, Maori and their animal allies exterminated the moa

and Europeans subsequently introduced pests such as deer and possums. This has changed the forest environment as plants are now subject to different grazing pressures than before — for instance, possums have caused the preferential decline of pohutukawa and rata.

Climate variation is also an important driver of change; it is worth noting that 10–12 ka, at the end of the last Pleistocene, even the Waikato was a tussockland, with continuous large forest only surviving in the far north and isolated refugia further south. Beech forest seems to have been slowly spreading over the axial ranges since the end of the Pleistocene, as has kauri in Northland; both may not have yet reached their 'climax range' since that climate change thousands of years ago; thus, the effects of the last glacial period are still with us. The cooling of the 'Little Ice Age' following the warmer medieval period may also have influenced our forests.

Now that global warming is taking place, further changes can be expected. Already in the Pureora State Forest fewer hard frosts have been noted in the last 50 years, allowing forest to reclaim some areas of frost-flat shrubland. Presumably, cold-intolerant species — both native and non-native — will be able to move south and uphill; this may drive some more cold-tolerant species so far uphill that they 'fall off the top' and disappear from our landscape.

opposite **Pohutukawa forest colonising a lava flow. Rangitoto Island, Auckland.**

top **In 2014, 128 years after its eruption, forest is creeping up the lower slopes of Mt Tarawera while the summit ridge is just being conquered by shrubs. Rotorua District.**

middle **Podocarp–hardwood forest of the Central Plateau, near Lake Okataina, one of our still-active caldera. Rotorua District.**

bottom **Large rimu in Pureora Forest Park, Ruapehu District. The previous hardwood-dominated forest on this site succumbed to the Taupo eruption almost 2000 years ago. Ruapehu District.**

CHAPTER SIX:

SCRUB AND SHRUBLANDS

INTRODUCTION

Shrublands and scrub, characterised by a canopy that rarely exceeds a height of 10 m, have become much more common throughout New Zealand since widespread forest clearance began with human settlement. Of course, some scrub and shrublands have always existed, as regrowth (secondary succession) after fire, tsunami or other natural catastrophes, on infertile or waterlogged soils, at altitude and near the coast. Given time and adequate dispersal of seeds, most modern scrub will eventually revert to forest except in the few places where the local conditions will not support that community, such as the kauri gumlands. It may take in the order of 100 years for the forest trees to overtop the scrub, cut off its direct supply to sunlight and cause it to regress, although even at that stage trees such as kauri and podocarps will still not have reached maturity.

Although in common parlance the terms 'scrub' and 'shrubland' are often used interchangeably, by definition scrub is dense vegetation with more than 80% of the canopy dominated by shrubs (plants with a trunk diameter of less than 10 cm at breast height), whereas shrublands have a more discontinuous canopy.

The vegetation of both scrub and shrublands is diverse and many exotic species have become part of the regeneration scene (the so-called 'adventive flora'); plants such as gorse, broom and privet are very common and thrive in our warm northern climate, often to the exclusion of native flora. The dominant component of native shrublands in the north is manuka (*Leptospermum scoparium*) and members of the kanuka complex (*Kunzea* species), often with an understorey of various species of *Coprosma* (e.g. karamu, *C. robusta*), fungi such as toadstools (evident especially in autumn), orchids, the poisonous

tutu (*Coriaria arborea*) and hebes such as koromiko (*Hebe stricta*). Other shrubs can include prickly mingimingi (*Leptecophylla juniperina*) and, south of East Cape and Mt Pirongia, the common tree daisy (*Olearia arborescens*). Tree ferns are also common, especially in moister areas.

left **Manuka scrub growing around previously cleared forest (note the dead trunks from times past): new conifers, in particular kauri, rimu and yellow-silver pine, are growing up and will eventually transform this into forest. Kauaeranga Valley ('The Pinnacles'), Thames-Coromandel District.**

HEATHS

Heaths refer to woody vegetation dominated by small trees and shrubs which are usually found in infertile areas or at altitude. Most natural scrub and shrubland falls into this category, as does the manuka and kanuka scrub of secondary succession, the exceptions being so-called 'temperate bush', which also often reclaims disturbed ground, and fernlands.

Heaths can be divided into three categories: tree-heaths, where the dominant species are more than 3 m tall (usually manuka and members of the kanuka complex); shrub-heaths at between 0.2 and 3 m; and dwarf-heaths at less than 0.2 m. The latter two may be referred to together as 'lower shrub-heaths'. In Britain and Australia in particular, the term 'heathland' is often used to refer to the stunted (often only 1–2 m tall), scrubby vegetation that may exist on infertile, often acidic soils, although we tend to include tree-heaths also.

Plants of the heathlands, such as manuka, can assume a variety of forms from tree-like to creeping mats. Their leaves are often sclerophyllous (small, hard, leathery and evergreen) to reduce water loss and help the plant survive hot, dry conditions. They may be ericoid (small, sharp-pointed and tough, like heather), needle-like or cupressoid (small, awl-shaped leaves which clasp the stem, like on a cypress). Many heathland plants belong to the heath (Ericaceae) family. As in forest, one can divide heathlands into layers; for instance, in a gumland manuka heath, manuka and *Dracophyllum* species may form the canopy, with an understorey of rush-like sedges and the fern *Gleichenia dicarpa* (pouched coral fern or tangle fern).

The most widespread heathlands in Northland are the kauri gumlands, which expanded after Polynesian and European fires cleared the original forest; they are susceptible to fire (although mountain flax, sedges and some ferns can resprout after fire and manuka seeding is promoted by it). Heathland vegetation is also present on the frost flats of the Central Plateau, on young

volcanic soils and on wet mineral soils. Heathland-type species (manuka, tamingi *Epacris pauciflora* and, less commonly, *Dracophyllum lessonianum*) may be present, usually as fringing species, around the Waikato peat wetlands. Tree-heaths can also be found at the salt-influenced coast and above the altitudinal limit of podocarp species on hills such as the summits of Mounts Pureora and Pirongia.

KAURI GUMLANDS

Kauri gumlands are a type of wet-heath found in areas previously occupied by kauri forest and characterised by ultra-infertile (usually podzolised) soils, with little peat. They are a distinctive and unique feature of the north, although much less common today due to 'development' for pasture or forestry, which has only been possible with great effort. Some of the best-remaining examples are on the Ahipara Plateau, above Ahipara.

Repeated fires in both Polynesian and European times have destroyed these ancient kauri forests; but the kauri, which grows well on soils that are infertile to begin with, leaves behind it an even more infertile soil. These acidic and strongly podzolised soils are associated with a hardened upper pan which forms a barrier to root growth, air and moisture, as mentioned in Chapter 2.

Species occurring in this habitat type are tolerant of very harsh environmental

top **An upland shrub-heath, near the summit of Mt Pirongia, Otorohanga District.**

bottom **A close-up of gumland species, including *Dracophyllum* species and stunted manuka. Ahipara Plateau, Far North District.**

left **Gumland landscape. Ahipara Plateau, Far North District.**

opposite **Frost-flat vegetation, silver tussock *(Poa cita)* being the grass and monoao *(Dracophyllum subulatum)* the shrub. Small plants, including mosses and lichens, thrive in the spaces between. Rangitaiki Conservation Area, Taupo District.**

conditions, and many, including species of fern, sundew, orchid and sedge, are seldom present in any other habitat type. Manuka (both *Leptospermum scoparium* var. *incanum* and other members of the *Leptospermum* complex) are the most dominant woody species in this habitat, but sedges (Cyperaceae) of the genera *Machaerina*, *Lepidosperma*, *Schoenus* and *Tetraria* as well as tangle fern (*Gleichenia microphylla* and *G. dicarpa*) are often dominant, and in some northern areas the uncommon king fern (*Todea barbara*) may be conspicuous. Other shrubs may include kumarahou or gum-digger's soap (*Pomaderris kumeraho*) and the heath shrubs *Dracophyllum lessonianum*, *Dracophyllum sinclarii*, soft mingimingi (*Leucopogon fasciculatus*) and tamingi. Orchids of the genera *Calochilus*, *Corybas*, *Microtis*, *Pterostylis* and *Thelymitra* are also prominent. In areas of poor drainage, acid peat bogs may form; these are usually dominated by *Machaerina* species sedges but also in places by the peat-forming wire rush (*Empodisma robustum*).

These lands were very important in the early days of European settlement as the source of the widely exploited kauri gum, once one of our most valuable exports.

NORTH CAPE

At North Cape, where there is a 120-hectare exposure of serpentinite (an ultramafic rock) on a windswept, fire-damaged plateau, a unique flora has evolved that is too complex to give proper credit to in this space. It is dominated by a mix of shrubs, including the endemic red-flowered *Hebe brevifolia*, dwarf forms of *Hebe ligustrifolia*, and endemic *Geniostoma ligustrifolium* var. *crassum* and var. *ligustrifolium* and hybrids between them. There are also several distinct races of manuka, wharawhara (*Astelia banksii*), a distinct race of houpara, rawiri (*Kunzea ericoides* var. *linearis*), prickly mingimingi and the endemic *Cassinia amoena*, *Coprosma spathulata* subsp. *hikuruana* and *Pittosporum*

pimeleoides subsp. *majus*. In places where the soil has been severely eroded, a sedgeland dominated by *Lepidosperma australe* and *L. neozelandicum* has replaced this heathland. Unique ultramafic forests are also present, dominated by a new species of tanekaha (*Phyllocladus trichomanoides*) and by pohutukawa (*Metrosideros excelsa*).

FROST FLATS

We like to think of ourselves as relatively warm, but there are parts of our uplands, especially in the vicinity of the Kaingaroa Plateau and Whirinaki Forest Park, as well as the Pureora Forest Park, that are as cold as anywhere in the country except Central Otago, and the vegetation there has been restricted accordingly. Frost flats are shrub-heaths and are most often found in depressions into which cold air drains in the night, as it is more dense (and therefore heavier) than warmer air (catabatic flow). Summer temperatures can drop to −5°C and in winter −18°C has been recorded, but in daytime the temperature can reach 30°C in summer as this inland area has a more continental climate than anywhere else in northern New Zealand. Once very widespread but now mostly converted into forestry, the largest remaining area is the Rangitaiki Conservation Area, just off State Highway 5 (the Napier–Taupo road). Such flats were originally created in the Taupo eruption 1800 years ago, as pumice from the eruption was washed down into valleys by rain, creating a flat surface within a depression. Probably, excessive water loss through the free-draining pumice, occasional but severe droughts, and the increased frequency of fires in such heaths as well as the cool temperatures all combined

in such depressions to exclude regrowth of our forest trees, particularly since they are relatively less tolerant of extreme cold and very poorly adapted to survive fire. Frost-flat vegetation then became more widespread with the arrival of Maori. The underlying pumice soil is naturally very infertile, hence the transformation of much of the Kaingaroa Plateau into exotic timberland rather than pasture, once the Forest Service managed to get such seedlings to survive in these cold hollows.

The dominant species are the red-brown shrub monoao (*Dracophyllum subulatum*), together with scattered silver tussock (*Poa cita*); fire may sweep through the shrubs from time to time so that it becomes a silver tussock grassland. Silver tussock, and other plants occasionally seen such as mingimingi (*Coprosma propinqua*) which are more indicative of semi-fertile sites, may be able to reach beneath the iron–humus pan to the pre-Taupo tephra. Makahikatoa (an as-yet unnamed species of *Kunzea*) and manuka are rare in the most extreme frost flats at Rangitaiki but more common on less-extreme flats. The groundcover includes the moss *Racomitrium lanuginosum* and the lichens *Cladia retipora* and, to a lesser degree, *Cladonia confusa*. Other hardy plants that survive in this area include mountain toatoa (*Phyllocladus alpinus*) and bog pine (*Halocarpus bidwillii*); these latter two species may once have been much more common and the current dominance of monoao may derive from monoao's better tolerance of human-induced fires, the original vegetation perhaps being a bog-pine heath. Smaller plants also present include the shrub patotara or dwarf mingimingi (*Leucopogon fraseri*) and grasses as well as liverworts, mosses and lichens.

Monoao is well placed to cope with infertility — it grows very slowly, has fungi on its roots to extract phosphorus and has sclerophyllous leaves to prevent desiccation. Every so often fire sweeps the flats, clearing mosses and lichens that have established in the meantime and allowing the monoao to regrow.

Unfortunately, exotic plants also stand ready to invade our few remaining frost flats, including lodgepole pine (*Pinus contorta*), mouse-ear hawkweed (*Pilosella officinarum*), gorse (*Ulex europaeus*) and broom (*Cytisus scoparius*). Nutrients released from top-dressing and through felling of the pine plantations adjacent to the flats enhance fertility, as do the nitrogen-fixing gorse and broom, thereby changing the environment.

Adjacent to and merging into the frost flat at Rangitaiki is a wet-heath of square sedge (*Lepidosperma australe*), tangle fern, monoao, wire rush (*Empodisma minus*), manuka and on the ground the mosses *Dicranoloma robustum*, *Campylopus* species and sphagnum moss. This is a similar vegetation type to the pakihi of the West Coast, developing on similarly severely leached soils with high water tables and dominated by tangle fern, manuka and rush-like sedges. There are also swampy areas with *Gleichenia* ferns, *Lepidosperma* and *Machaerina* sedges (or grasses such as *Carex* species, *Austroderia toetoe* and *Hierochloe redolens* in flushed areas), and more turf-like patches with comb sedge (*Oreobolus pectinatus*) or the threatened *Carex rubicunda* in temporary pools of water.

Grey scrub (a scrub, rather than a heath, of divaricating shrubs, especially rich in *Coprosma* species) can also be seen in frost hollows on more fertile tephra; common species include mingimingi (*Coprosma propinqua* var. *propinqua*) and twiggy tree daisy (*Olearia virgata*). Like the monoao heaths of poorer soils, this scrub is probably a fire-tolerant derivative of bog-pine heaths. It assumes a grey colour due to the way the tangled, divaricating branches tend to hide the green colour of the small leaves.

KANUKA AND MANUKA SCRUB

Perhaps the scrub vegetation most familiar to the average New Zealander, manuka and members of the kanuka complex are our pioneer woody plants. Manuka can send forth light seedlings which are widely dispersed by wind when they are only 5 cm high; both plants are light-tolerant and grow quickly and prolifically, and manuka in particular can tolerate a wide variety of environments from dry ridges to wet heathlands. Kanuka is variable, with some races being typical early pioneering plants that are rapidly replaced by taller broadleaved trees while a few can and do form their own forest type, especially in sand country (some may grow up to 30 m tall). That aside, these manuka and kanuka 'scrublands' are usually transient communities, although the lack of seeds from other forest trees along with browsing, frequent fires and harsh environments can perpetuate them. Although naturalised shrubs such as *Hakea* (from Australia), gorse, broom and brush wattle (*Paraserianthes lophantha*, from Western Australia) have replaced them in areas, manuka and kanuka scrublands still remain important.

Manuka and kanuka are particularly well adapted to thriving in conditions where the forest has been removed, letting light down to the ground; for instance, they produce huge numbers of seeds when the plants are still very young. Manuka is perhaps the hardiest of our plants, able to grow in almost any climate from the salt-sprayed and windswept coast of the Waitakere Ranges to upland bogs in Pureora Forest Park and dry rocky ledges.

below **Kanuka (*Kunzea* species) scrub, near Awanui, Far North District.**

left **A wind-exposed site; even manuka can only survive in the relative shelter of the valley. Cape Reinga, Far North District.**

Manuka can be distinguished from most members of the kanuka complex by its smaller size when fully grown (6 m rather than 30 m, smaller on less-well-suited sites), its larger flowers, borne singly in the leaf axis and with fewer stamens, together with its sharp-tipped leaves (when one brushes past it, it is more prickly). Manuka also has long-persistent and larger fruiting capsules ('nuts') that are often indehiscent — the capsules do not necessarily split open in a predetermined way at maturity; they may not open until they are more than a year old, or when there is a fire. In contrast, the dehiscent fruits of kanuka open within 2–3 months of flowering and usually fall from the parent plant once the seed has been dispersed. Manuka is more often covered by a sooty mould, which is nourished by the sugary excretions of an introduced scale insect. Kanuka flowers around midsummer; manuka flowers a bit earlier and also at other times. Both provide shelter for seedlings of the larger forest trees to survive and grow; when the larger trees overtop them, they block the light necessary for these pioneering species to survive.

In somewhat neglected grazed pasture it is common to find tall, open manuka stands. In association with such stands there may also be smaller *Coprosma*, *Leucopogon* and *Leptecophylla* shrubs; grasses such as *Microlaena stipoides* and *Oplismenus hirtellus*; and the rasp fern/pukupuku (*Doodia australis*). Given appropriate nearby seed sources, if left undisturbed tree seedlings will invade, especially totara (*Podocarpus totara*), mapou (*Myrsine australis*) and tanekaha, eventually overtopping the manuka and transforming the scrub into forest.

In northern Te Urewera, a mixture of kanuka and kamahi (*Weinmannia racemosa*) has replaced some areas of forest after fire; however, broadleaves get eaten by deer and kamahi is killed by fire, leaving stands of kanuka in places with a sparse understorey of the grass *Microlaena avenacea* and hook sedge (*Uncinia uncinata*) as well as tree ferns.

Dry, exposed sites with little topsoil, such as on some islands of the Hauraki Gulf, may also support stunted manuka and kanuka heath with not much more understorey than just lichens, mosses and a few small plants such as prickly mingimingi.

TAUHINU SHRUBLAND

Ozothamnus leptophyllus (tauhinu), a weed of hill-country grassland, is often found by the coast; it tends to invade grassland beyond the dispersal of manuka but is quickly succeeded by longer-lived plants. It may grow in association with coastal shrub daisy (*Olearia solandri*), manuka, hebes, coprosmas, dracophyllums and other species, or by itself. Some authorities recognise an ultramafic endemic at North Cape, *Cassinia amoena*.

SCRUB IN GEOTHERMAL AREAS

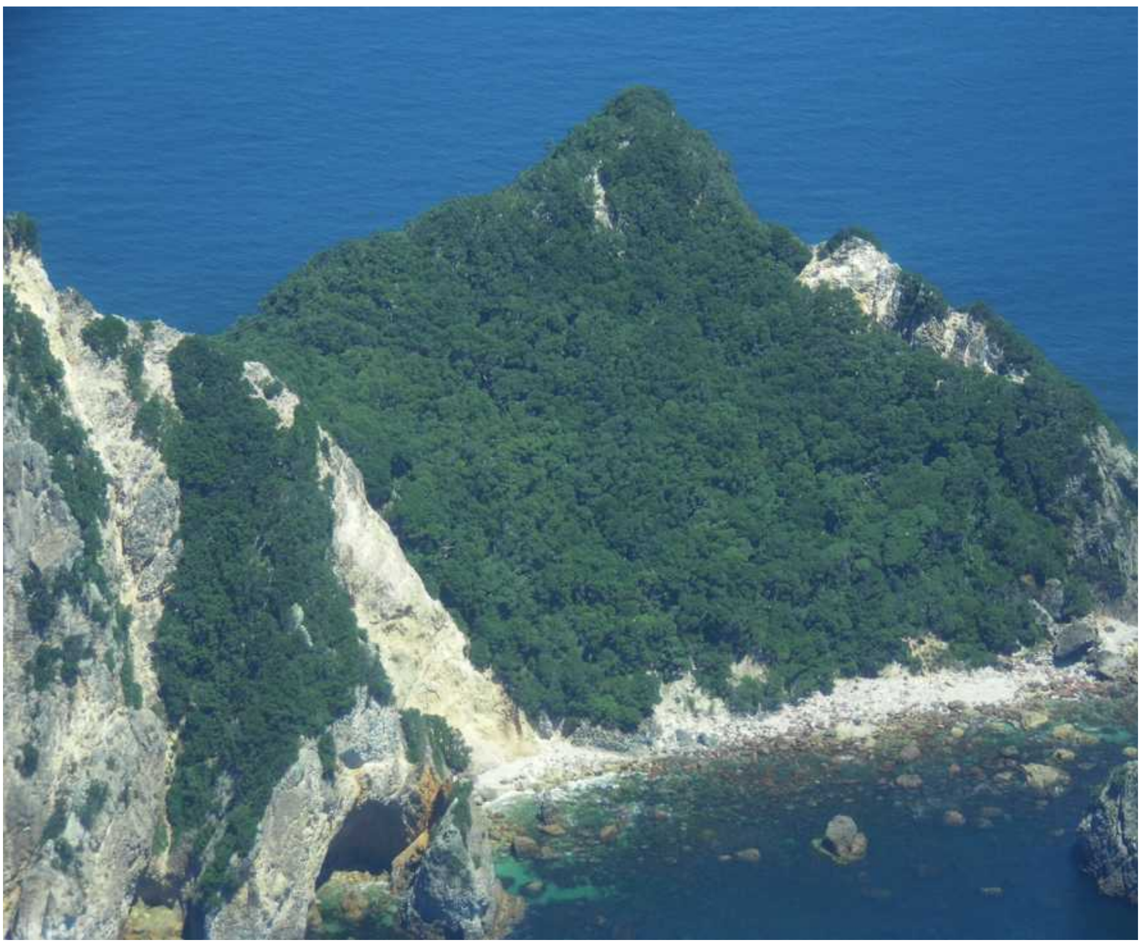
Plants can only survive in areas close to geothermal activity (a very rare habitat on a global scale) if they can tolerate warm soil, acidic soils and toxic minerals; as the soil temperature rises, forest thins out into scrub and, finally, bare ground. A kanuka (*Kunzea ericoides* var. *microflora*) endemic to geothermal areas is often dominant and may grow in tree, shrub or prostrate forms — some of which are genetically fixed (i.e. all the individuals in one particular population share the same form (allele) of a particular gene; for example, if the people in one town were to all have blue eyes because no one has the brown form of the eye-colour gene) on the heated soils — although even this cannot survive in soil temperatures above 50°C, and when the temperature at 5 cm below the surface is between 40°C and 50°C they can only grow to a maximum of 30 cm high.

left **Some stunted kanuka scrub manages to survive on higher, slightly cooler ground at the edge of what is viable. Waimangu Valley, Rotorua District.**

Less-well-adapted erect trees such as pines can be pushed over by the wind with relative ease, because their root systems either don't penetrate the hot soil enough to provide good anchorage or, if they do penetrate it and steam escapes, the tree dies. Other common plants include manuka, mingimingi and monoao; mingimingi dominates the very acidic soils (due to abundant sulfur) at Tikitere. The warmth also means that, on less-acidic sites (e.g. Waimangu Valley), the tropical ferns *Dicranopteris linearis* and *Nephrolepis flexuosa* can survive at this latitude (which marks their worldwide southern limit), and in hot streams and springs one often finds the geothermal race of *Christella dentata*, another tropical fern. Waiotapu also has ferns, such as the thermal swamp fern *Cyclosorus interruptus*, as well as New Zealand flax (*Phormium tenax*) and raupo (*Typha orientalis*) in very wet areas, although sedges are most commonly dominant near the hot-spots. Seasonally one may find the beautiful bearded copper orchids *Calochilus paludosus* and *C. robertsonii* (e.g. in Whakarewarewa and on Rainbow Mountain), and in one place the flying duck orchid (*Paracaleana minor*).

The tropical clubmoss *Lycopodiella cernua* and some mosses, liverworts and lichens can survive where soil temperatures at 5 cm down are above 50°C, but even moss cannot tolerate conditions at soil temperatures of 97°C.

below **Coastal scrub. Aldermen Islands, Thames-Coromandel District.**



COASTAL SCRUB

Scrubland is commonly encountered around our coast, where wind and salt spray combine to stunt the vegetation. It has been described in more detail under 'Coastal forests' in Chapter 5 and Chapter 9.

DISTURBED GROUND (TEMPERATE BUSH)

On disturbed ground, apart from members of the kanuka complex and manuka other short-lived trees are also common, including wineberry (*Aristotelia serrata*), *Pseudopanax* and *Pittosporum* species, coprosmas, rangiora (*Brachyglottis repanda*), hebes and tutu (*Coriaria arborea*). Tree ferns, sprouting from rhizomes and trunks, and cabbage trees (*Cordyline australis*) are also often abundant. Together these plants form a nursery for the seedlings of taller plants that will persist in the subcanopy of the taller forest that will eventually succeed it, such as mahoe (*Melicytus ramiflorus*), lancewood (*Pseudopanax crassifolius*), karaka (*Corynocarpus laevigatus*), kohekohe (*Dysoxylum spectabile*) and fuchsia (*Fuchsia excorticata*). The nursery plants eventually become less common as these subcanopy plants and the even taller large forest trees gradually overtop them and take over, as long as nearby seed sources remain so that the forest can regenerate, although the tree ferns usually persist in our generally moist forests (they die back later in drier locations).

Forest lianes can also be abundant in coastal bush and after forest disturbance. Such species may include *Rubus* species (e.g. bush lawyer, *Rubus cissoides*), *Muehlenbeckia australis* and *M. complexa* (which often smothers small trees), and *Parsonia* and *Clematis* species. The understorey can include species common to taller forest as well as remnants from earlier stages, such as bracken (*Pteridium esculentum*). Ferns are also often common, given the generally fertile nature of this rejuvenated ground.

However, when the original cover has been disturbed, introduced species may also get a toe-hold; when they become able to perpetuate themselves in the wild they are termed naturalised. In northern New Zealand, common naturalised species include woolly nightshade (*Solanum mauritianum*), Chinese privet (*Ligustrum sinese*) and thickets of the garden hybrid *Elaeagnus* x *reflexa*. Brush wattle, a legume that grows into a tree, is a particular scourge in Northland. Invasive grasses and herbs of importance in our area include species such as arum lily (*Zantedeschia aethiopica*), wild ginger (*Hedychium gardneranium*), elephant grass (*Arundo donax*), the pampas grasses *Cortaderia selloana* and *C. jubata*, climbing asparagus (*Asparagus scandens*), tutsan

(*Hypericum androsaemum*), and foxglove (*Digitalis purpurea*).

Other naturalised shrubs include tree lupin (*Lupinus arboreus*), extensively planted on coastal dunes, and tree lucerne (*Cytisus proliferus*), present on some cliffs and coastline as well as around Lake Taupo. Blue pea or dally pine (*Psoralea pinnata*) has colonised Northland.

As trees develop in this shrubland they form thickets which may be dominated by large exotic trees such as tree privet (*Ligustrum lucidum*) and black wattle (*Acacia mearnsii*); privet stands may be able to persist indefinitely and may never be replaced by native forest. The total list of exotic species is indeed enormous and continues to increase; in New Zealand as a whole they outnumber the natives. The Auckland region in particular is a mecca for naturalised exotic species, given its warm, tolerable climate and its position as a first port of call for many new species, many of which are garden escapees.

Some naturalised species have more redeeming features than others, in particular the nitrogen-fixers gorse and introduced broom (there are also native nitrogen-fixers including kowhai, *Sophora* species, and native brooms, *Carmichaelia* species). Gorse seeds have been scattered throughout the country by machinery, water and animals; they stay dormant for decades when buried but then rapidly grow when on the surface. They become established on open ground and need moderately fertile soils, especially those containing phosphorus. Heavy close grazing will eliminate the seedlings and dense vegetation excludes them; therefore they are found on sites such as floodplains and erosion-prone hill pastures where both are lacking. Although a perennial enemy of farmers, gorse can pave the way for a return to native species. Gorse is a single-generation plant that enriches the soil with nitrogen; this and the shelter provided by the gorse then allows native ferns, cabbage trees, karamu and others to establish and overtop it with time. Broom is similar in many respects to gorse, although it is more tolerant of drier and frostier sites.

Some of these naturalised species have adaptations that, after multiple clearances and loss of the native seed bank, may enable them to become the dominant species — for instance, the seeds of gorse and broom may survive for decades; both also resprout after fire and disperse their seeds widely. *Hakea*, an Australian genus of which some species have become naturalised here, can form dense, exclusive colonies.

Finally, as discovered on Tiritiri Matangi Island in the early stages of its conversion from farmland, when it was thought that forest cover might establish in pasture by itself, long grass and associated herbaceous species resist invasion by seeds of trees and shrubs except where it is overtopped by adjacent tree canopies, such as those of manuka, which suppresses grassland along its margin.

FERNLANDS

Bracken is common up to 800 m altitude on sunny slopes, preferring well-drained soils (such as alluvium and pumice soils) and disliking swamps, shallow soils and gley podzols. In pre-European times its permanent habitat was probably confined to coastal and inland dunes, but it would have temporarily covered extensive areas following volcanic eruptions on the Volcanic Plateau and, following repeated Maori fires, permanently occupied large swaths of the countryside such as the Waikato; despite its vulnerability to fire, it can recover vigorously from its deep rhizomes. It was an important food source for Maori.

Tree ferns can all resprout after burning. Species that are commonly seen include mamaku/black tree fern (*Cyathea medullaris*), common in fern-choked damp gullies; wheki (*Dicksonia squarrosa*) in rough pasture; and ponga/silver fern (*C. dealbata*) beneath tall kanuka. Mamaku in particular is then often colonised by epiphytic seedlings of tree species such as *Weinmannia* (e.g. kamahi), *Griselinia* (e.g. broadleaf) and five-finger (*Pseudopanax arboreus*).

above **Fernland. Papakura, Auckland.**

CHAPTER SEVEN:

THE TERRESTRIAL FAUNA OF THE NORTH

INTRODUCTION

Our land animals, at least those that live outside the coast or inland wetlands, are overwhelmingly creatures of the forest, given the dominance of that environment and the absence of other habitats such as high alpine environments (only a few peaks emerge just above the treeline), deserts or, at least prior to forest clearance, grasslands. Hence it seems appropriate to place a discussion of land animals at this juncture.

There are several common themes repeated over and over again in many of our animals, be they invertebrates, reptiles or birds.

- Being an island, some animal groups (whether whole classes of animal or just families) have been able to reach here and others have not; those that 'made it' have often then evolved into many different species (undergone widespread radiation) to fill niches that in more continental locations might already be occupied. The most obvious example is the lack of native mammals and the occupation of niches such as those of large ground-dwelling herbivores by birds such as the kiwi and moa as well as insects such as the giant weta; but the same is true for many groups, including some families within even a single insect order.

- Adoption of ground-based niches has led to gigantism and flightlessness in a relatively large number of our animal species. Usually

this has then led to an increased chance of getting caught by introduced predators.

- These changes mean that we have many endemic species (species only occurring in New Zealand) — 52% of our entire biota, according to one source.

- With the arrival of man and his assortment of introduced species, many native species have become extinct, due to predation by creatures against which they have not evolved defences, competition for food with other introduced species, and habitat loss; others have become confined to small remnant populations, often on predator-free islands.

- Some exotic species have been deliberately introduced — often to subsequently cause problems — but most are accidental arrivals. Parasites and parasitoids have often arrived along with their host species.

- Modified environments such as urban areas, gardens and pasture are often more suitable for introduced animals than natives.

- More exotic species continue to arrive on a regular basis, often through our ports and airports which have a greater volume of international traffic than most other parts of the country and therefore have a greater number of arrivals; moreover, they often survive better in the north than elsewhere in New Zealand if they come, as many do, from a warmer climate than New Zealand's.

INVERTEBRATES

Often the forgotten element in our ecology, invertebrates are nevertheless a vital component of any healthy ecosystem. A recent estimate suggests that we may have 80,000 different invertebrate species inhabiting our land, freshwater and marine environments; 20,000 of these are insects. We have only catalogued a very small fraction of this number, so there remains much to discover. There may be 230 times as many invertebrate species as vertebrates and 40 times as many endemic vascular plants; of these, perhaps 80–90% are only found here. Most evolved from Gondwanan ancestors, most commonly arriving on the prevailing westerly winds from our nearest continental neighbour, Australia. We are an invertebrate hot-spot, with perhaps 2% of the world's invertebrates being endemic to New Zealand.

Like some native birds, some invertebrates have evolved to become large, ground-dwelling and flightless, for instance the giant weta, the tusked weta and giant weevils; in many cases this has imperilled their survival. Often their main defence mechanism is to stand still, a useful defence against native predators such as birds but not against mammals that hunt by smell as well as sight, including rats, mice, possums and hedgehogs. Perhaps 20% of our flora is endangered and we must assume that a similar proportion of our invertebrate fauna is also threatened, although we don't really know.

Another common theme is the introduction, mostly accidental, of large portions of our invertebrate fauna; a few have been brought in deliberately to target other pests — often invertebrates themselves! Parasitic species have also often arrived as a consequence of their host's introduction. Many exotic species have proven to be more competitive than natives in the modified landscapes and habitats we now have of pasture, buildings and mammals.

Interestingly, the central North Island has pretty much the lowest invertebrate species diversity of anywhere in New Zealand. This may relate to the major geological cataclysms that have struck this area in relatively recent

times, such as the volcanic eruptions of the Taupo Volcanic Zone, which have affected this region more than any. In particular, the Nelson–Marlborough region has a far greater diversity of invertebrates (that region is particularly diverse in molluscs), as does southern New Zealand (i.e. Otago and Southland), probably because like Nelson-Marlborough it is a large, stable landmass that has been emergent for a long period of geological time and has a diverse range of habitats, from the arid expanses of Central Otago to the high mountains and rainforests of the west. Otago and Southland also evaded the glacial periods of the Pleistocene much better than Canterbury and Westland even though they are further south. It should therefore come as no surprise that southern New Zealand has the greatest invertebrate diversity when molluscs are excluded, and that the older and geologically more stable Northland is more diverse than the central North Island.

Not only are many of our invertebrates hunted by introduced predators, but they are also threatened by competition with other introduced species (for instance, other browsers, including related exotic species and completely unrelated ones — such as deer) and by loss of habitat, thanks mostly to human activity. Significant loss of our invertebrate fauna has repercussions beyond the invertebrate world; often, native invertebrates have evolved alongside other species, such as plants, and play an important role in necessary functions such as propagation of native plant seeds that is impossible for introduced species. Of course, they are not always so benign to their fellow New Zealanders . . .

INVERTEBRATES OF THE NORTH

There are many different phyla of invertebrates, but just one (phylum Chordata) that includes all vertebrates, which is indicative of the great diversity of invertebrates that exists. Many invertebrate phyla are exclusively marine or at most coastal (e.g. echinoderms, which include starfish and their relatives) and are not listed here; many more are predominantly marine or perhaps live in freshwater, but include some terrestrial species. Often in these phyla the marine species are not particularly unique to New Zealand but those that live in freshwater or on land have a very high degree of endemism, particularly at a species level, because of our isolation from other landmasses. Their marine relatives, by contrast, can arrive on our shores from almost any other marine environment on the planet with relative ease and, as a result, the degree of endemism is much lower.

As well as many native species there are also a large number of exotic species, both deliberately and accidentally introduced; in general, the diversity of the native fauna is much greater in any one group but the invaders are often very successful and prominent, especially in modified environments such as pasture and urban

areas. Many invertebrates are tiny, even microscopic, and easily missed. However, the invertebrates that one can potentially encounter on our landmass include those discussed below.

EARTHWORMS

Our native segmented worms (phylum Annelida) may well represent a link between Gondwana and the present day, as earthworms cannot cross saltwater and thus it would seem unlikely that they could have arrived here after the separation of Gondwana; we have around 173 different native species of earthworm (family Megascolecidae), with relatives in South America, the Falkland Islands, Australia, South Africa and New Caledonia — i.e. a Gondwanan distribution. The largest is the North Auckland worm (*Spenceriella gigantea*), which can reach 1.4 m long and 11 mm wide and burrow more than 3.5 m deep. However, the worms one usually finds in one's garden are introduced, from the family Lumbricidae.

Earthworms are among the most ancient land animals; their ancestors probably were present in the Precambrian, around 650–750 million years ago (Ma). They are included in the subclass Oligochaeta (oligochaetes); their predominantly marine and coastal relatives, also annelids, are Polychaeta (polychaetes or bristleworms).

PERIPATUS

Peripatus, or velvet worms, have changed little over the last 550 million years; sometimes one calls such creatures 'living fossils'. They are the sole representatives of the phylum Onychophora. In New Zealand this phylum is represented by two genera, *Peripatoides* and *Ooperipatellus*, with around 30 species in total, the most common being *Peripatoides*

above ***Peripatus novaezealandiae*, the common New Zealand peripatus. Photograph: Paddy Ryan.**

novaezealandiae, especially in our part of the country. Caterpillar-like, these miniature carnivores capture their prey with sticky spit. Characterised by their unjointed, stumpy walking limbs, these nocturnal inhabitants of the forest floor may represent a missing link between the annelids and the greatest group of invertebrates, the arthropods. Their thin skin confines them to moist places, as they are prone to drying out (desiccation).

ARTHROPODS

The arthropods (phylum Arthropoda) includes, by one common definition, the subphyla Chelicerata (the largest class of which is Arachnidae, i.e. spiders, mites and their kin), Crustacea, Myriapoda (centipedes and millipedes) and, of particular importance on land, Hexapoda (Greek for six legs or feet; the same word (*podi* or *πόδι*) can mean either foot or leg); the latter includes class Insecta, far and away the most prominent group of terrestrial invertebrates in northern New Zealand and indeed anywhere in the world. This phylum also includes the now extinct trilobites (Trilobitomorpha).

Characteristic of arthropods is a body plan consisting of jointed limbs and jointed bodies.

Although divided into segments in a similar fashion to annelids, some segments have a completely different form and function from others, with fusion of different segments into larger, specialised 'tagmata' (e.g. the head vs the thorax of an insect). The skeleton, or supporting framework, is found on the outside of the animal (an exoskeleton), unlike vertebrates which have an endoskeleton.

AN OVERVIEW OF INSECTS

Insects (i.e. those hexapods, or six-legged arthropods, with 11 abdominal segments — the vast majority of hexapods) comprise the most diverse group of phylum Arthropoda. Some orders are more diverse than others, particularly the more highly evolved groups. Beetles in particular are an amazingly diverse group of creatures; for instance, we have at least 25 species of stag beetle (often found under rotting logs in beech forest, their larvae living within the rotten wood). Acting both as predator and as prey, hence deeply enmeshed in the ecosystem, insects are also involved in pollination of flowers and recycling of nutrients. Indeed, members of the orders Lepidoptera (butterflies and moths) and Diptera (flies) are the major pollinators of our flowers, often not as specifically as in other parts of the world (the flowers here are less choosy as to exactly which insect pollinates them); New Zealand has more 'primitive' moths associated with fungi, lichens, lower plants and detritus rather than those associated with flowers, probably due to its lower floristic diversity.

Flightlessness is also a feature of some insects, including moths (usually females) as well as beetles, wasps, cockroaches, earwigs and stoneflies. Outside of northern New Zealand, in the mountainous windy alpine areas of the south and on the subantarctic islands, it becomes even more common.

Insects are particularly prominent in

below **Manuka in flower in August. Kai Iwi lakes, Kaipara District. We do not have the great floral displays often seen in other parts of the world; even manuka, which puts on one of our best showings, has rather drab white flowers as they rely on a more diverse, less evolved and less species-specific range of animals for pollination.**

left **Ants gathering honeydew from aphids, Auckland. Photograph: Simon Franicevic.**

forest, soil and freshwater environments but they are also common in brackish water and on the beach as well as at altitude; the crustaceans, however, outdo them in the marine environment.

Insects come in many different varieties. In the forest, those that feed off live plants are either eaters of plants (such as weta, grasshoppers, millipedes, caterpillars, beetles and stick insects) or suckers of plant sap (such as planthoppers, scale insects and cicadas). Herbivorous insects feed not only on flowers and living leaves but also on decaying vegetation. One can often find chewed leaves, the legacy of a caterpillar or beetle's nocturnal feast, galls and wilted foliage as evidence of their presence. Some caterpillars are camouflaged to resemble twigs or even a beech leaf.

Honeydew is a sugary excretion produced by certain organisms, mainly insects, including some scale insects and aphids as well as a few caterpillars and even fungi; it provides nourishment for other animals, such as in the case of aphids. New Zealand's most famous 'honeydew story' describes the cycle in which the sooty scale insect (*Ultracoelostoma assimile*) feeds on the sap of beech, excreting the excess as honeydew which in turn nourishes both insects and organisms; some of the latter include nitrogen-fixing bacteria from which the tree derives nutrition — going the full circle! This beneficial situation reaches its apex in the forests of the northern South Island and southern North Island, where wasps feeding on the honeydew are a particular problem, rather than northern New Zealand.

Not all insects are herbivores, however; among the largest carnivores are the mainly arboreal praying mantises, one of which is native. The introduced vespid wasps (especially *Vespula germanica*, the German wasp, and *V. vulgaris*, the common wasp) of our beech forests are particularly devastating carnivores, feeding on other insects as well as competing for food with native invertebrates (e.g. by eating honeydew); this interruption of the food chain in turn affects native birds and other higher-order predators. Other insects are parasitic; in fact, as we shall discover, there are many families of parasitic and parasitoid wasps.

Some insects, mainly introduced ones

but also some natives, can be real pests in other ways. Aucklanders will remember the successful eradication campaigns of the white-spotted tussock moth (*Orgyia thyellina*) and painted apple moth (*Teia anartoides*), introduced into that region in the 1990s, to save our horticultural industry from their attentions. Manuka blight, caused by the Australian scale insect *Eriococcus orariensis*, attacks the tree of the same name. Many other introduced mites, aphids, butterflies, moths and others plague gardeners, horticulturalists and orchardists alike. Similarly, grasslands are attacked by the stem weevil (*Hyperodes bonariensis*) and black field cricket (*Teleogryllus commodus*), as well as native grass grubs (mainly *Cotelytra zealandica*) and porina moths (*Wiseana* species), which find our ryegrass–clover swards to be the perfect environment.

Conversely, many invertebrates (especially the small parasitic wasps) have been accidentally or even deliberately introduced along with their hosts and may keep those introduced host species under control, and are thus an asset.

Insects are divided into those that do not undergo a metamorphosis but instead grow up without changing form, similar to humans; those that undergo a partial metamorphosis from nymph to adult (hemimetabolic); and those, perhaps the most frequently encountered group and certainly the most diverse and numerous, such as butterflies, that undergo a complete metamorphosis from larva to adult via a pupa (holometabolous). The last group tends to be the more recently evolved and those that do not metamorphose the more ancient (or, some might say, primitive). Presumably, the ability to change form allows them to conquer more environments, timing their metamorphosis to complement changing conditions such as different seasons. This may explain why the variety of insects in the holometabolous families tend to be greater.

The various insect orders will now be considered, with the older orders discussed first and the more recent ones later. Further details of insects which, for at least part of their lifecycle, are aquatic can be found in Chapter 8.

NON-METAMORPHOSING AND HEMIMETABOLIC INSECTS

Bristletails and silverfish

Two primitive flightless insect orders include the bristletails (Archaeognatha), found on many offshore Northland islands, and silverfish (Thysanura) — of which we have many natives. However, it is the introduced *Lepisma saccharina* that is the most notable, as it feeds on books and clothes.

Mayflies and stoneflies

Northern New Zealand has a particularly diverse mayfly fauna (order Ephemeroptera), which lives around freshwater, especially in the smaller headwaters of forested streams (the most diverse recorded to date being in the Waitakere River catchment, where 28 species have been found — more than twice as many as in the entire South Island, mostly the grazing Leptophlebiidae). Mayflies usually inhabit unpolluted running waters and hence can be an indicator of water quality; they do not inhabit still waters such as lakes. Our mayfly fauna is also a more Cretaceous 'Gondwana-like' one than in other southern landmasses, Australia having been invaded by more-tropical species. Conversely, stoneflies (order Plecoptera, which earn their name by hiding under the stones of stream floodplains in winter) are not particularly abundant in northern New Zealand as they generally prefer cooler climates.

Dragonflies and damselflies

The most agile of all flying insects are the dragonflies and damselflies (order Odonata); New Zealand has a relatively low diversity of Odonata fauna but those we have are distinctive. Both the aquatic nymphs and the adults prey on other insects and small animals, although in turn they are predated by spiders, tui and other natives as well as introduced predators such as cats and rats.

above **Red damselfly, Auckland. Photograph: Simon Francicevic.**

Cockroaches

One of the most disliked of all insect orders must be Blattodea, the cockroaches. They are an ancient order of which we are lucky enough to have 31 native (probably all endemic) species, and unlucky enough to have 13 introduced varieties. Most natives are flightless or poor flyers but are very adaptable creatures, living anywhere from lowland forest to above the snowline; they can even be found on our subantarctic islands. In northern New Zealand, much work remains to be done on them and the discovery of new species is entirely possible. Two introduced cockroaches are widespread in northern New Zealand and have spread from it to other parts of the country — the German cockroach (*Blattella germanica*) and the Gisborne cockroach (*Drymaplaneta semivitta*); there is also a more recent Australian arrival into Auckland, *Drymaplaneta heydeniana*, which is spreading further afield with great rapidity. All are pests of built environments. Auckland also has seen four other introduced species, although one, *Periplaneta americana*, is only here for teaching and research purposes and cannot survive outside controlled or other warm environments, such as tyre factories. Another introduced cockroach, *Paratemnopteryx couloniana*, has not managed to get more than a few hundred metres from its original site of introduction in Auckland (there is a similar cockroach in a similar situation that was introduced to Dunedin; not all can spread like wildfire).

Termites

New Zealand also has a handful of termites (infraorder Isoptera) — three endemic species as well as a few Australians; the native species are probably mostly creatures of the forest, some feeding on damp wood and others on dry. However, the native *Kalotermes brouni* can also feed on untreated wood in buildings, fence posts and power poles! In nature, of course, the breakdown of wood is vital to the recycling of essential nutrients in the forest.

Praying mantises

There is only one native species of the order Mantodea, *Orthodera novaezealandiae*, which lives in both forest and scrub environments as well as in our gardens. Praying mantises are, for the invertebrate world, large predators, consuming flies, moths and even wasps; particularly beneficial is their predilection for aphids. In turn they provide sustenance for vertebrates such as birds, skinks, bats and cats. The South African *Miomantis caffra* is our second mantis and has spread from its initial site in New Lynn, Auckland to the Waikato and Bay of Plenty (as well as to Blenheim in the South Island), displacing the natives in urban areas especially.

Earwigs

New Zealand has 13 native earwigs (order Dermaptera), some of which are found on our offshore islands (e.g. the Mokohinau and Poor Knights islands), despite them being wingless; the European *Forficula auricularia* is a pest of our fruit growers, although its numbers appear to have declined with the spread of hedgehogs!

Weta, crickets and grasshoppers

A diverse and interesting order is Orthoptera, which includes weta, grasshoppers, crickets and similar animals.

Weta probably justify the appellation 'iconic New Zealanders', although there are still many gaps in our knowledge of them — including how many different species there are and whether these species are endangered or not! Another example of a 'living fossil', their fossilised Triassic ancestors from 200 Ma are strikingly similar. We divide weta into two families, the cave or jumping weta (Rhaphidophoridae) and the family Anostostomatidae, which includes tree, giant and ground weta.

Cave weta, of which New Zealand has about 50 species, tend to be smaller, with smaller eyes and duller colours but longer antennae. They live not only in caves but also in other dark and humid places such as under stones and in logs. Tree weta, which are widespread on the mainland even in urban areas (perhaps your garage!), also prefer dark conditions, being generally nocturnal; the rasping sound they make by striking their

top **South African praying mantis (*Miomantis caffra*). Photograph: Simon Francicevic.**

middle **A katydid — a member of family Tettigoniidae, distinguished from grasshoppers by their extremely long antennae. Photograph: Simon Francicevic.**

bottom **Giant weta, Aorangi, Poor Knights Islands, December 1984. Crown Copyright, Department of Conservation: Te Papa Atawhai, 2005.**

ridged abdomen with their hind legs is a characteristic sound of our nocturnal bush. The weta found in northern New Zealand is named the Auckland tree weta, *Hemideina thoracica*. Both cave and tree weta can jump surprisingly long distances. Both may be omnivorous, although tree weta are mainly herbivorous; some would consider them an ecological equivalent of mice.

Rarer are the giant weta (*Deinacrida* species), which usually weigh up to around 35 g and are 20 cm in overall length (10 cm body length). One gravid specimen of the largest, the Little Barrier giant weta or wetapunga (*D. fallai*), has been recorded as weighing 72 g — three times the weight of a mouse and more than a sparrow; it can probably claim to be the heaviest recorded insect worldwide! Once widespread in our North Island lowlands but now virtually extinct, another species, *D. mahoenui*, was found in a patch of bush near Te Kuiti (it also exists in several other sites in the Waikato and the Coromandel as well as on two rat-free offshore islands). It has survived by living under a gorse bush canopy, resting in the dead debris of the bushes during the daytime and coming out to feed at night, thus avoiding predation by rats.

The large tusked weta are also much more endangered than the smaller tree weta, on a similar level to most of the giant weta; there are three species hanging on in northern New Zealand — one in isolated spots in Northland, one on Middle Mercury Island and the other in the Raukumara Range.

Northern New Zealand is also the main home in New Zealand of the introduced large black cricket, present in gardens, lawns and pastures; we also have native species of crickets and grasshoppers, most of which prefer open grassland and scrub. Our crickets are silent, rather than rubbing their wings together to make noise. We also have the world's only flightless mole cricket (*Triamescaptor aotea*).

Stick insects

Of the order Phasmatodea we only have stick insects; elsewhere in the world leaf insects are also part of this order. Stick insects are long, slow, flightless (at least, those that live in New Zealand), night-feeding herbivores which dwell in all vegetation types; all species

left **A stick insect, Port Fitzroy on Great Barrier Island, Auckland.**

are endemic. Being of tropical origin, they are usually found below 900 m altitude and many of New Zealand's stick insect species can be found in our (relatively warm) part of the country, although not all. Being nocturnal helps to protect them from predation, which is often by birds, although they also fall prey to the ship rat, which can climb the trees they live in. Tuatara and lizards are also known to eat stick insects.

Bugs, cicadas, aphids and other plant-sucking insects

Hemiptera is the largest order of hemimetabolic insects, i.e. those insects that have a young (nymph) similar in appearance to the adult, albeit wingless, and an incomplete metamorphosis not involving a pupa. These 'juice-sucking' insects include the suborders Sternorrhyncha (including the superfamily Aphidoidea — mostly aphids), Auchenorrhyncha (cicadas, spittlebugs, leafhoppers and planthoppers), Coleorrhyncha (moss bugs) and Heteroptera (bugs). Most feed on sap from vascular plants, either phloem, xylem or both, although there are exceptions. One exception are the assassin bugs (suborder Heteroptera, family Reduviidae), which feed on other insects and some even on blood (e.g. bed bugs).

- Suborder Sternorrhyncha includes plant-sucking insects, such as scale insects, white flies and jumping plant-lice (psyllids) — whiteflies and scale insects are important economic plant pests but, as mentioned previously, are also involved in the manufacture of honeydew. Aphids also feast on plants, sucking the phloem, and are often host-specific; 90% are not endemic and they can be major economic pests.

- The suborder Auchenorrhyncha includes a major part of the plant-eating insect fauna. They have piercing and sucking mouthparts to

below **Cicada. Photograph: Simon Francicevic.**

feed on plant phloem or xylem and plant cells as well as mosses and fungi; some species are significant plant pests or are vectors for plant diseases. They are diurnal and live in most open and forested habitats, both on the ground and above it. Northland in particular has a large number of local endemic species, although overall a greater diversity of native species live in the South Island than in the North Island. Auckland also harbours many introduced species; these often have fully developed wings and a better ability to live in a more modified environment.

- One Auchenorrhyncha family, the cicadas (Cicadidae), are very familiar due to their loud summer song; most North Island species are forest-dwellers although some may also appear in urban areas, including *Notopsalta sericea* (the clay-bank cicada) and *Amphispsalta* species, the clapping cicadas. Cicadas live underground as nymphs for about 3–5 years, feeding on plant roots, emerging to live as adults for 2–4 months. They provide food for many species, including kiwi.

- Rounding out the infraorder Cicadomorpha are several other Auchenorrhyncha families. These include spittlebugs (Aphrophoridae), the largest of which is the North Island endemic *Pseudaphronella jactator* of subalpine and montane environments (others live in trees and shrubs such as *Coprosma* species); leafhoppers (family Cicadellidae), a very diverse group in New Zealand and a source of some agricultural pests; and ground-dwelling leafhoppers (family *Myerslopiidae*) which, appropriately given the name, inhabit the leaf litter and other ground debris in our forests.

- The other Auchenorrhyncha infraorder is Fulgoromorpha, the planthoppers. Many of these have nymphs that may, at least in part, subsist on fungi and are often found in or on the

top **The passionvine planthopper (*Scolypopa australis*, an introduced member of the suborder Auchenorrhyncha). Auckland.**

middle **New Zealand vegetable bug (*Glaucias amyoti)*, a member of the family Pentatomidae that includes the shield or stink bugs (part of the suborder Heteroptera). Photograph: Simon Franicevic.**

bottom **Green shield bug on *Coprosma*, Te Muri, Mahurangi, Auckland. Photograph: Simon Franicevic.**

forest floor; the adults feed on plant phloem. The passionvine planthopper (*Scolypopa australis*), an Australian introduction, is a pest of vines such as kiwifruit; it may also feed on poisonous tutu, secreting a honeydew that bees then incorporate into honey which in turn becomes dangerous to humans.

Other suborders of Hemiptera include the moss bugs and the 'true bugs'.

- Moss bugs (suborder Coleorrhyncha) are tiny wingless bugs about 2–5 mm long that live in water-saturated moss and liverworts, a relic of Gondwana. The North Island has three species (out of nine in New Zealand), although none are endemic to the north as they also live in other parts of the country.

- Suborder Heteroptera, true bugs, is particularly diverse and numerous here; New Zealand has 305 species, 249 of which are endemic (although only 20% are endemic to the North Island; Northland, though, is a centre of bug diversity), although this pales against the world number of at least 39,000 and probably much more. Our bugs' closest relations tend to live in southeastern continental Australia, followed by Tasmania, Norfolk and Lord Howe islands and southern Chile. More than 90% of our native bugs are strictly terrestrial and 25% are flightless. The natives have mostly now been excluded from coastal lowlands by introduced bugs, especially near our trading ports and in the agricultural regions of Northland, Auckland, Gisborne and the Bay of Plenty. Most feed on sap from vascular plants, seeds or pollen, with some also feeding on fungi, insects and other arthropods (such as the assassin bugs, mentioned previously). There are a few native pests, although they are not particularly important as such; overseas introductions, however, have the potential to be devastating as many overseas species are serious agricultural pests.

Thrips

The thrips comprise the order Thysanoptera; they are small, slender insects that feed mainly on leaves but also on flowers, with some eating fungi, and are, in turn, predated by native wasps. The native *Thrips obscuratus* has proven to be a major stonefruit pest. Thrips tend to be more common in beech than in podocarp–broadleaf forest.

Booklice, barklice and psocids

The order Psocoptera comprises the psocids, booklice and barklice, small insects between 1 and 10 mm in length. This is a relatively little-studied order; we know that some live in leaf litter and others in granaries and buildings, but no doubt a lot more remains to be found out about them. They are certainly important as grazers of microflora and occur in large populations.

Lice

Lice form the order Phthiraptera: flat-bodied, wingless ectoparasites of birds and mammals. They are obligate parasites and detrimental to their hosts — chewing or sucking on them — humans being no exception. As one would expect, most of our native species parasitise birds.

HOLOMETABOLOUS INSECTS

Dobsonflies

The dobsonflies (order Megaloptera) are the most primitive of the holometabolous insects. We have but one species, *Archichauliodes diversus* (the toebiter), which lives in stony and gravelly streams, its larvae predominantly feeding on mayflies and midges with a flying adult form. They are the largest insects of running water and are also important in the diet of freshwater fish.

Lacewings

Lacewings (order Neuroptera) are relatively uncommon in New Zealand, although there have also been introductions, including the most commonly encountered, *Micromus tasmaniae* (from Australia). Lacewing larvae feed on other insects such as aphids, weta, ants, flies and woodlice as well as spiders; they become prey of insectivorous vertebrates such as fantails. Because some feed on horticultural pests such as aphids (as well as other beetles and suchlike), there have been attempts to deliberately introduce some species.

Beetles

The order Coleoptera, the beetles, make up a fifth to a quarter of the world's insect fauna numbers. There may be perhaps as many as 300,000 to 450,000 species worldwide; they are particularly important as predators.

One of the most distinctive features of beetles is their hardened forewings (elytra) which protect their hindwings and abdomen and open to allow flight; some beetles, however, are flightless with vestigial hindwings and, on occasion, fused elytra. These hard elytra probably aid their survival in environments too severe for those with exposed and fragile wings, and reduce water loss in dry conditions. However, this system means that although many can fly, they are not as gifted fliers as many other insect orders. New Zealand contains at least 5000 and perhaps around 10,000 species, some being old Gondwana species that have been here for many millions of years and some having arrived more recently from neighbouring countries — this type of fauna is termed disharmonic. There is one family (Chaetosomatidae) that only occurs in New Zealand and Madagascar! Some families have more than 1000 New Zealand endemic species (Staphylinidae, Curculioinidae) while others have only one (e.g. Eucinetidae); almost all native beetles are endemic but, as with other orders, these natives have often lost out to introduced species in modified landscapes such as gardens.

Of all environments, beetles reach their greatest diversity in our forests. Very few are marine, although there are seashore beetles as well as freshwater aquatic and semiaquatic beetles; some also live in shrub and grassland. The northern North Island is an area of high endemism; many beetle species are regionalised or restricted to certain communities (e.g. caves).

Beetles occupy many niches; some are predators, while others are herbivorous or feed on fungi, particularly shelf and bracket fungi (the Ciidae attack almost all bracket fungi), with mushrooms and toadstools being less vulnerable. Some live under loose bark on native trees and feed on plant tissues or moulds therein (e.g. Colyidiidae and stag beetle (Lucanidae) larvae), while others just seek shelter in such locations. Yet more live in decaying and rotting wood, serving to break it down.

Beetles can be big or small, with the heaviest being the huhu (*Prionoplus reticularis*) and the longest the giraffe weevil (*Lasiorhynchus barbicornis*) — up to 80 mm long. Conversely, adult beetles of the feather-winged family (Ptiliidae) can be as small as a quarter of a millimetre and are among the smallest of all insects.

The huhu beetle (a type of longhorn beetle, family Cerambycidae, characterised by their long antennae and slender bodies) is an iconic New Zealand insect; the up to 70-mm-long white larvae (huhu grubs), which feed on the dead wood of 14 gymnosperms and two angiosperms (the introduced black wattle, *Acacia mearnsii* and the native tawa, *Beilshmiedia tawa*) in lowland podocarp forest as well as exotic pine plantations, are even considered a delicacy by some, tasting

somewhat like chicken or peanut butter (apparently!).

Perhaps the most commonly encountered beetles are the ladybirds (Coccinellidae), some of which feed on aphids, mites and scale insects and are therefore useful as a biological control; for instance, *Rodolia cardinalis* is capable of reducing cottony cushion scale on citrus to very low levels.

The Carabidae (ground beetles) are the largest group of predator beetles; they are often large but flightless, and therefore can have a limited range, but their long slender legs allow them to run quickly. Other predatory beetles include rove beetles (Staphylinidae) and tiger beetles (Cicindelinae); wireworm larvae (family Elateridae) can also predate other animals.

Woodborer beetles, both native and introduced (and particularly the introduced *Anobium punctatum*), are well known to householders but important in nature as they can break down dry wood and allow

top **A huhu beetle, *Prionoplus reticularis*. Photograph: Simon Franicevic.**

bottom **Ladybug nymph eating oleander aphids. Photograph: Simon Franicevic.**

above **A longhorn beetle. Photograph: Simon Franicevic.**

wood-rotting fungi to do their job. Other woodborers, both native and introduced, attack the wood of pines, eucalypts and macrocarpa (*Cupressus macrocarpa*), including that of our buildings, the natives having previously fed on a diet of native tree stumps and suchlike.

A favoured habitat for many beetles is leaf litter; the larvae of scarab beetles (Scarabaeidae) often live in the soil, feeding on plant roots and as noted above one particular economically important scarab beetle larva, grass grub (the larva of *Costelytra zealandica*), has adapted well to pasture, where it can occur in massive numbers and as a result is a well-known agricultural pest.

Other common beetles include weevils (superfamily Circulionoidea) and aquatic beetles such as the carnivorous diving beetles (Dytiscidae), which inhabit streams and ponds; some aquatic beetles live in this environment as both larvae and adults, others only for part of their lifecycle.

Fleas

Fleas, order Siphonaptera, are obligate blood-sucking parasites of warm-blooded vertebrates. Globally most focus on mammals, but unsurprisingly the native New Zealand species include only one mammalian specialist (that mammal being a bat) and 22 bird parasites, especially of seabirds. However, many have arrived with their introduced hosts — including humans.

Flies

Flies, not only the archetypal blowflies but also mosquitoes, midges and many others, all belong to the order Diptera (two-winged), so-named because their hindwings are relatively vestigial although they may be important aerodynamically. Many flies, such as craneflies and hoverflies, are actually very handsome creatures. Much maligned, they fulfil some very important functions in the ecosystem, including:

- pollination — although they are less efficient than bees, since they drop more pollen and do not rely on flowers as their sole food source; they are prominent on smaller and more open-flowered natives such as rata, cabbage tree, manuka and kanuka
- control of noxious weeds — some species have been imported for control of certain weeds
- nutrient recycling — flies are important digesters of carrion and dung (there are also fungus gnats in the forest that feed on fungi); mammals the size of possums and larger tend to provide the highest percentage of flystrike species

- predation of pests, such as grass grub and white butterfly caterpillars on cabbages; some flies are also parasitic on other invertebrates

- food, especially for bush birds (insectivores such as fantails), spiders and other invertebrates.

It is also useful to note that all the major pest species are introduced — so we're to blame — and only 0.5% of the 3325 species known in New Zealand are pests! Most introductions have come from Europe (71–72%) or Australia (21%). Very significant pests they can be, however, and flystrike caused by blowfly species (mainly *Lucilia* species and *Calliphora stygia*) can kill sheep. Other flies include herbivores that attack crops; in northern New Zealand the root-feeding Australian soldier fly (*Inopus rubriceps*) is of particular importance in pasture and maize. Gall midges and leafminers damage flowers and others can be found in commercial mushrooms. Many readers will also have heard of fruit flies (of the family Tephritidae), being much in the news in recent years.

The fly population, as with all animals, is controlled by a combination of predators, pathogens, parasites and parasitoids. Important predators include the previously mentioned bush birds, spiders and other invertebrates; nematodes and protozoal parasites as well as fungal and bacterial pathogens also have a massive effect on the fly population. Parasitoids, mainly wasps of the order Hymenoptera (the main parasites of arthropods generally), kill the host before it matures; such insects may prove to be an important means of biological control.

Flies are a very diverse lot — there are two suborders of Diptera, Nematocera and Brachycera. Within each division there are tens of families of flies. Hence, they comprise the second-most diverse order of insects after the beetles, with perhaps 120,000 species worldwide (although Hymenoptera also comes close to this number). Some are very small and some, such as blowflies and daddy long-legs, are, by invertebrate standards, very large.

Nematocera often live in leaf litter and dead wood; they tend to prefer moister areas and some are aquatic. Many are important fungus feeders, although some are predators; particular highlights include the following.

- The New Zealand glow-worm (*Arachnocampa luminosa*) is a predator, the larvae of which use light to attract prey in caves and dark overhangs in forested regions, especially in the wetter west. It is the maggot of a fly rather than a worm.

- The Sciaridae (fungus gnats) are among the most abundant insects in beech, podocarp and pine forest as well as wet pasture; some are also horticultural pests.

- There are three families of cranefly, many of which prefer wetter places.

- The Cecidomyiidae (gall midges), of which there are probably a few hundred species, are important in forest and scrub, their larvae feeding inside plants and causing abnormal growths called galls.

- Midges (Chriondomidae) used to be attracted to Auckland's Mangere oxidation ponds in swarms; thankfully the sewage treatment there has now been changed and the large ponds no longer exist. Most midges are inhabitants of freshwater but some are terrestrial.

- The most likely to bite a human are members of the family Simuliidae, the blackflies and sandflies. The most annoying to humans in the north is the blackfly *Austrosimulium australense*; we are fortunate not to have

A. ungulatum, found predominantly on the South Island's West Coast.

- Mosquitoes (Culicidae) breed in freshwater, usually slowly moving or standing. All four introduced species and five out of the 12 natives bite humans; the most widespread is a native, *Culex pervigilans*. Others include the Australian striped mosquito (*Aedes notoscriptus*), which is spreading out of Auckland, and the native *A. antipodeus* or winter mosquito, which can remain active in cooler weather. None currently transmit any human disease, although those mosquitoes already present would be able to spread certain diseases should they arrive. Luckily, we have no mosquitoes capable of transmitting malaria.

- The Anisopodidae include the outhouse flies or wood gnats (*Sylvicola* species) which inhabit rotting vegetation, wet manure or fallen vegetation in water; *Sylvicola neozelandicus* is the species particularly associated with long-drop toilets in forested areas, as they breed in wet manure.

- The net-winged midges, Blephariceridae, often dwell near turbulent bouldery streams but are not present north of Te Aroha (where *Peritheates harrisi* has been recorded).

- The family Tipulidae are more commonly known as craneflies and daddy long-legs. Some can swarm, but none bite and none are particularly significant for humans. Their larvae are very important, however, as they break down vegetable litter in forests, swamps, bogs and streams and a few predate worms. They often take inorganic matter to which unicellular algae, bacteria or fungi are attached; *Zelandotipula* larvae, for instance, feed on the last remnants of soft, decayed vegetable matter by streams and seepages. This family has a high rate of endemism but, unlike many endemic species, tends to be quite tolerant of human modifications to its environment. For instance, *Limonia vicarians* is common in household gardens and *Chlorotipula albistigma* can be found in rotting willow, Monterey pine (*Pinus radiata*) and other exotics. One, *Trimicra pilipes*, has an almost worldwide distribution. Compared with other countries, more are

left **Craneflies, a member of the family Tipulidae. Photograph: Simon Franicevic.**

flightless (about 10%) and we have a surprisingly diverse intertidal population. Indeed, *Limonia kermadecensis* can be so common around Auckland that its short burrows probably contribute significantly to the degradation of some of our soft mudstone shorelines.

The other fly suborder is Brachycera. Some tend to favour moist habitats, such as seepages and freshwater, although these families also include soil predators, beach inhabitants and even spider parasites.

- One very diverse fly family is the Dolichopodidae. Some live in grassland while others feed on insects attracted to honeydew on manuka.

- The robber flies (Asilidae), which look like large wasps, are the only insects to catch their insect prey in mid-air.

- Stratiomyidae, or soldier flies, are often found standing sentry on flowers; they are quite similar in appearance to hoverflies and wasps. As already mentioned, one Australian import, *Inopus rubriceps*, is an important pasture pest. Most soldier flies breed in leaf litter and soil and feed on decaying leaf litter.

- The large horse-flies, which live mostly in moister sites, are members of the family Tabanidae. Their bites can be more painful than those of mosquitoes, as they slash open the skin with a scissoring motion of their knife-like mouthparts.

- There has been but one known specimen (*Kaurimyia thorpei* gen. et sp. nov.) of the family Apsilocephalidae found in the north, in kauri forest; another was found in Dunedin.

However, the majority of flies in Brachycera are found in the infraorder Muscomorpha (members of which are often unofficially referred to as Cyclorrhapha), which is itself divided into two sections. Section Aschiza includes the following.

- Hoverflies or flower flies (Syrphidae) are large patterned insects; two introduced species mimic bees. They mainly feed on decomposing material in wet sites but may also predate invertebrates such as caterpillars and aphids.

- Phoridae are small hump-backed flies (‘scuttle flies’, as they tend to run rather than fly away from danger) which are mostly forest-dwelling scavengers and mushroom-feeders.

The other section of Muscomorpha, Schizophora, comprises 78 families worldwide, divided into two subsections. The subsection Acalyptratae, the acalyptrate flies (lacking calypters, a part of the forewing), is a very diverse group, important families of which include those listed below:

- The Agromyzidae. The larvae of these small flies feed on leaves, often only of a very few plants (i.e. they are very host-specific), and therefore are potentially useful as biological controls. Angiosperm species as diverse as mahoe (*Melicytus ramiflorus*), tree nettle (*Urtica ferox*), *Juncus* species rushes and *Coprosma* species may all be attacked by these little creatures.

- Chloropidae are also small flies but are very common. They include *Apotropina tonnoiri*, a characteristic fly of the beach, and *Gaurax* species, often found in gardens.

- Shore flies, Ephydridae, often have aquatic or semi-aquatic larvae, although those of the genus *Hydrellia* are terrestrial consumers of grasses and rushes.

- The Drosophilidae or fruit flies, which many might remember from school science, we have relatively few of. They are actually more associated with the yeasts of ripe and rotting fruit than the fruits themselves.

- The lesser dung flies, Sphaeroceridae, can be very abundant, feeding on grass clippings, in freshwater shorelines and on other decaying vegetation.

- Sciomyzidae, marsh flies, have larvae that feed on snails.

- Another family, also called fruit flies (although only a few feed on fruit) is the Tephritidae. The endemic species feed predominantly on flowers and seed heads. They are small flies, with three indigenous genera and five species introduced as biological controls for weeds. They can also be very serious pests of fruit — an accidental introduction of the Mediterranean fruit fly (*Ceratitis capitata*) in Auckland, fortunately eradicated in 1996, resulted in nations such as China banning the importation of New Zealand fruit for a year. Hence the disposal bins in our international airports before one goes through customs — and the stiff fines afterwards.

- Some forest flies include the Helosciomyzidae and the Teratomyzidae fern flies — we know that the adults at least feed on ferns, but what the larvae feed on is unknown.

- Small flies of the families Australimyzidae, Canacidae, Coelopidae and Helcomyzidae are mostly found on seashores, e.g. the kelp flies (family Coelopidae) breed in rotting seaweed; they can be very abundant, although some species are only found in the South Island.

- *Pseudopomyza* species have been tentatively associated with bird dung, but are also attracted to rotten fruit.

- Many other families are represented by just one or two introduced species — e.g. two species of Chamaemyiidae have been introduced for the control of scale insects in fruit crops and gum trees.

Calyprate flies (subsection Calyptratae) include house flies and blowflies (including some which are vertebrate ectoparasites and others whose larvae are endoparasites of invertebrates). There are only five native families but also several introduced ones, including the following.

- Muscidae, of which there are four common introduced species, including the house fly (*Musca domestica*). Their larvae often feed on other insects, e.g. shore fly larvae of seashore driftwood and invertebrates living in rotting wood.

- The blowflies, Calliphoridae, include three prominent pest species which were accidental introductions and which can have severe impacts on pastoral farming, causing flystrike.

- The striped dung fly (*Oxysarcodexia varia*) is widespread in open country; the dung flies comprise the family Sarcophagidae.

- Tachinidae are parasites of other insects. The parasitoid Australian leaf-roller fly (*Trigonospila brevifacies*) was introduced to northern New Zealand initially to control the light brown apple moth (*Epiphyas postvittana*); they are successful enemies of pest lepidopterans (butterflies and wasps).

- Fanniidae, which includes the lesser house fly (*Fannia canicularis*) and others, may be useful in forensics, since their larvae live in decaying organic matter, including homicide victims.

- *Botanophila jacobeae*, an Anthomyiidae, was

left **A blowfly (family Calliphoridae); this is probably a green bottle fly *Lucilia sericata*, a significant cause of flystrike in sheep. Photograph: Simon Franicevic.**

introduced unsuccesfully to control ragwort by feeding on its seed.

- There are also four louse flies (Hippoboscidae) that affect birds.

Our native flies have links with Australia, Chile, New Caledonia and Norfolk Island, with some genera more diverse here than in those other places while others are more limited; 27 fly species are considered endangered. Parasitic flies with endangered hosts, sensitive aquatic species and large predator flies that live in soil most of their immature life and are therefore not mobile (Therevidae, Asilidae) are likely to be the most vulnerable. But, on the whole, most fly species are less vulnerable than large flightless insects such as weta, ground beetles and some weevils, which are decidedly more likely to end up as rodent food.

Strepsiptera

We only have two 'twisted-winged' insects, parasites of other insects; these include *Coriophagus casui*, which has been found in Auckland close to restored bush and members of the kanuka complex of plants.

Wasps, sawflies, ants and bees: order Hymenoptera

This holometabolous order is one of the most morphologically diverse, with around 115,000 described Hymenoptera species worldwide; the New Zealand fauna is poorly known, but we must have a minimum of 1500 different species of which the majority are probably endemic. It can be divided into two suborders, the more primitive Symphyta (sawflies and wood wasps, most of which have caterpillar-like larvae that feed on leaves) and Apocrita, which itself is split into two groups, the parasitic Parasitica and the stinging Aculeata.

Aculeata includes the non-parasitic wasps as well as ants and bees, 'aculeate' meaning that they possess a sting. Ants, because of their large numbers, are very important in controlling vegetation. We actually have very few aculeate and symphytan species; for instance, we have only 40 species of ant, of which only 11 are endemic; all five vespid wasp species are introduced.

By comparison, Parasitica is more well represented in New Zealand, but still there are some notable absences. These parasitic wasps are important since, by parasitising other insects, they regulate those insect populations; as a result, they are the insects most commonly used as biological controls. They are often very tiny and are also the most diverse group of insects within this order.

Some characteristics of our hymenopterous fauna include the following.

- A high proportion of flightless or short-winged (brachypterous) species, especially in females. Wing reduction tends to be associated with living in wet forests, seasonally damp environments or alpine locations.

- A high degree of intraspecific variation (variation within the same species) across New Zealand.

- There are significant numbers of alien species. The Asian paper wasp (*Polistes chinensis*) is a significant nuisance in urban areas, as are the invasive ants *Pheidole megacephala* (the big-headed ant) and *Linepithema humile* (the Argentine ant). The big-headed ant has only been reported from the Auckland and Kermadec regions and will be limited in its further spread by its tropical nature; it is, however, one of the worst garden, horticultural and house pests. The Argentine ant has made its way to the island sanctuary of Tiritiri Matangi Island; it is also a domestic and commercial nuisance and has a deleterious effect on native fauna. Another nuisance ant of urban areas is the white-footed ant (*Technomyrmex albipes*), originally from Asia.

- Set against the overwhelmingly negative alien species listed above, alien parasitic species may sometimes be beneficial; often they arrive with the pest species that they parasitise and, in doing so, help control their numbers. However, some parasites may also affect non-target native species.

- Some alien species have been deliberately introduced to control weeds and arthropod pests, as already alluded to. We also have four species of bumblebee and the honey bee (*Apis mellifera*), all introduced, which are very important economically as pollinators (bumblebees pollinating red clover and lucerne).

Compared with honey bees, all of our approximately 40 species of native bee are smaller than honey bees in size and relatively more primitive, divided only into males and females rather than having queens and worker bees. Together with flies (Diptera), native bees (Colledidae) assist with pollination of angiosperms.

below **Bumblebee. Photograph: Simon Franicevic.**

Caddisflies

Caddisflies (order Trichoptera) constitute a significant portion of our freshwater fauna; nearly all have aquatic larvae (a few live in damp ground instead) and they fulfil many different roles in the food chain — some are predators, some feed on algae, some on decomposing vegetation, some on the periphyton (microflora of stone surfaces), and yet others are filter feeders from water currents. All streams, trickles and seepages contain them — even those in farmland — but of all freshwater bodies it is the medium-sized streams in untouched forest that support the most diversity and this is a good indicator of stream purity. The adult needs liquid to survive and may approach flowers; most are nocturnal and come freely to light. Highly endemic (73%), some of the most prominent species in New Zealand are the cocoon makers (of the family Hydrobiosidae).

Moths and butterflies

Since moths and butterflies (and their larvae, i.e. caterpillars) are easily observable macroscopically, historically order Lepidoptera is one of the best-studied insect orders. Worldwide, most Lepidoptera larvae feed on flowering plants (angiosperms), often having just the one host. However, more primitive moths are more likely to be associated with ‘lower’ plants such as liverworts, algae and moss or even other vegetative matter, including fungi, lichens and organic detritus in the leaf litter; these species are relatively common in New Zealand and hence we tend to have a more ‘generalist’ population than many other countries. Of course, the term ‘primitive’ could be considered pejorative; it is equally true to say that we have a number of families with an ancient lineage. Interestingly, we also have an abundance of coloured, diurnal moths as opposed to drab, nocturnal ones.

Members of this order are important both as pollinators and as prey food, particularly for insectivorous birds; for instance, the morepork (*Ninox novaeseelandiae*) is known to predate the puriri moth (*Aenetus virescens*); moths are also a significant food source for our nocturnal geckos. Spiders are probably their most significant invertebrate predator and they may host insect parasitoid larvae, especially from the orders Hymenoptera and Diptera. Caterpillars also exert grazing pressure on plants; often one can spot caterpillar holes in large-leaved plants, such as those made in kawakawa by the kawakawa looper (*Cleora scriptaria*).

Some of our endemic species are significant horticultural pests. These include the leaf-rollers (Tortricidae) which feed on orchard trees, and the larvae of some *Wiseana* species (porina moth) that compete with stock for spring pasture growth. Exotic pest species include the white-spotted tussock moth and the painted apple moth (*Teia anartoides*), both of which were accidentally introduced to Auckland, in 1996 and 1999, respectively. Both are defoliators of orchards and commercial forest trees and may also threaten native forests; both were subsequently sprayed with bacterial pathogens (*Bacillus thuringiensis* var. *kurstaki*, a pathogen of such lepidopteran larvae).

In total, New Zealand has around 17–20 species of butterfly (not all have been described) and 2000 moth species. Most are natives and 92% of New Zealand’s species are endemic; not a few are endangered and presumably some have become extinct that we just don’t know about. Our biggest moth is the aforementioned puriri or ghost moth, the largest moth in our one endemic moth family and unique to the North Island with a wingspan of up to 150 mm. Despite their size, they only live for 2 days, between the months of October and December. New Zealand also has more copper butterflies than elsewhere, whose larvae

above **White butterfly (*Pieris rapae*). Photograph: Simon Franicevic.**

feed only on *Muehlenbeckia* species. However, although we have the biggest moth, in general diversity increases as one heads further south.

Perhaps the most commonly encountered member of this order is the monarch butterfly (*Danaus plexippus*); it self-introduced after milkweeds (plants of the family Asclepiadoideae) were planted here.

As with other insects, we also have pest species, including some natives such as the porina moth of pasture and lawns. We have also introduced some species to control plant pests; the gorse seed-pod moth (*Cydia succedana*) has been successfully established on gorse as a biological control.

There are also 72 introduced species (four butterflies and 68 moths), including the common cabbage white butterfly (*Pieris rapae*); Australia is the most common source country. Vagrants are also occasionally blown over from Australia.

OTHER ARTHROPODS

Other hexapods

As already mentioned, hexapods are the six-legged arthropods, of which the vast majority are members of class Insecta. However, there are other members of the Hexapoda subphylum, including the myriad varieties of springtails, still poorly described in New Zealand but very common and present in almost all environments, on the forest floor in particular. They tend to be small, white and between 0.2 and 10 mm in length, feeding on micro-organisms around roots, decomposing organic matter, water surfaces, fungi and plants. The simplest living hexapods, the coneheads (class Protura) are also found in humid places such as acid soil and rotten wood, breaking down and recycling organic nutrients, and can be associated with fungi; three species have been reported from Little Barrier Island although none from the eastern half of the North Island. They appear to be more abundant in pine plantations and may reflect the health of that environment. A member of the class Diplura has also been found in the Poor Knights Islands.

Chelicerates — spiders and their relatives

Chelicerates are distinguished by their lack of antennae, pincers or fangs rather than mandibles, and their single rather than compound eyes. Two classes, including the most primitive, horseshoe crabs (class Xiphosura), are marine. Horseshoe crabs are not currently found in New Zealand, although there have been accidental introductions to Auckland's Waitemata Harbour and the waters around Great Barrier Island which have subsequently become locally extinct. Sea spiders (class Pycnogonida) are and can be found intertidally as well as at sea, under boulders and among seaweed.

However, class Arachnida is the largest and includes, in New Zealand, spiders, mites, ticks, harvestmen and pseudoscorpions; fortunately, we do not have any true scorpions. Most of these species are terrestrial, although some mites in particular may be both freshwater and marine; spiders are the most common

above **A jumping spider. Photograph: Simon Franicevic.**

right **Spiderweb. Mt Pirongia (northeastern slopes), Waipa District.**

member of this class. In general, spiders use venom to aid in capturing their prey (with the exception, in New Zealand, of the orb-weaving spider *Waitkera waitakerensis*). However, in the north there is only one spider, the native katipo (*Latrodectus katipo*, the female usually being black in the northern North Island and red further south, although they are the same species), that is harmful to humans. White-tailed spiders, of which we have two Australian imports (*Lampona* species), give painful bites but these are not thought to be harmful. New Zealand has a very diverse spider fauna with probably around the same number of native spider species (1700 known, 2500 estimated) as the continental United States and far more than the similarly sized United Kingdom (700); 1628 are endemic, 27 native but not endemic and 37 exotic.

Mites and ticks (Acari) live in almost all possible habitats, including the deep ocean to which insects have not yet penetrated. Two prominent species of mite include the house dust mite (*Dermatophagoides pteronyssinus*), which lives in our homes and is a potent cause of asthma, and a face mite *Demodex folliculorum*, which causes blepharitis (red, irritable eyelid margins). Most mites are tiny, measuring less than 1 mm long, and, as the above examples testify, are often important agricultural and human pests. Most recently, the accidental introduction of the honey bee

parasitic mite *Varroa destructor* has cost the bee and related industries hundreds of millions of dollars. Ticks are slightly larger than mites and also include important pest species such as the economically damaging cattle-tick *Haemaphysalis bispinosa*. They can be quite species-specific; for instance, one native tick is restricted to tuatara, and other mites and ticks may be found on and within the digestive system of other native animals, both vertebrates and invertebrates.

Harvestmen (order Opiliones) are notable for their tiny bodies and enormously long legs, the most frequently encountered being *Phalangium opilio* (one of many species colloquially called 'daddy long-legs'); it is a European import but we also have hundreds of native species. Ninety-four per cent of our native pseudoscorpions are endemic to New Zealand and, despite the name, they are not particularly close relatives of true scorpions. Both pseudoscorpions and harvestmen live predominantly in the leaf litter, as well as in the soil.

Myriapods

Centipedes and millipedes, the most common myriapods, are also inhabitants of the humid forest floor, both the leaf litter and soil; they prefer this environment as they have a hard but not waterproof cuticle so are prone to drying out. Some can also be found in caves, where they are often pale and have reduced or absent eyes but longer antennae and legs. Some of our North Island millipedes may measure 10 cm in length (*Eumastigonus* species); others are only a few millimetres. Millipedes (class Diplopoda) chew pieces of rotting wood, leaving behind smaller pieces more easily recycled by bacteria, and are hence probably at least as important as earthworms in the recycling of such organic debris, particularly in New Zealand where earthworms tend to be more dwellers of leaf litter than burrowers. Centipedes (class Chilopoda), on the other hand, are predators, often killing their prey by injecting them with poison. As well as the above two classes there are also two less frequently encountered myriapod classes, Pauropoda and Symphyla, whose members are generally smaller.

Crustaceans

Crustaceans (with the notable and very common exception of slaters, as well as some amphipods) are generally either coastal or aquatic and feature heavily in Chapter 8; they have a body usually divided into two sections, a thorax and an abdomen, plus a five-segmented head, multiple limbs and two antennae. They are very diverse and numerous; copepods, the oar-footed, may be the most numerous animals on Earth, mostly because they dominate both marine and freshwater plankton although they can be found in any humid environment, such as forest litter and damp moss, often in a parasitic or symbiotic relationship with other organisms.

Slaters, woodlice and pillbugs are all members of the suborder Oniscidea; most prefer the damp as they need to keep their pleopods (abdominal legs) damp for respiration, so they inhabit environments such as rotting logs and decaying leaves but are all exclusively terrestrial. As well as native slaters we have many introduced species, mainly from Europe. They are a type of isopod, a group characterised by a predominantly vertically flattened appearance, as opposed to the horizontally flattened (i.e. squashed sideways) amphipods. Although slaters and their kin are exclusively terrestrial, the majority of isopods are marine and the group includes organisms such as sea lice and the woodborers of wooden piles, wharves and ships.

All terrestrial amphipods ('landhoppers') are members of the Talitridae family; they

may inhabit forest floors, gardens and grasslands in burrows, under leaf litter, trees or rocks. However, the majority of Talitridae are either coastal (beach fleas or sandhoppers), freshwater or marine, although they can survive out of water for longer than other amphipods.

PHYLUM CNIDARIA

Even this very marine phylum — an ancient one that includes corals and jellyfish, contains some terrestrial members (some members of class Myxozoa), although they subsist in the almost marine environment of a living host, as a parasite.

PHYLUM PLATYHELMINTHES

Flatworms, tapeworms and flukes are mostly parasites. There are also some that can be found living in leaf litter or decaying logs as well as in streams, usually hiding in dark places away from bright light, such as under rocks and weeds.

PHYLUM GNATHIFERA

This is a very large phylum of very small animals, including some worm-like animals and rotifers. Most are marine, but rotifers can be found in any place that holds water for a few days — including damp moss — and are not just confined to marine plankton. The thorny-headed worms (class Acanthocephala) are all parasites, living in vertebrate intestines as adults.

MOLLUSCS

The forest floor is a rich environment of decaying vegetation and is the habitat of our land snails and slugs (gastropods), the terrestrial representatives of phylum Mollusca. New Zealand has 906 terrestrial species of mollusc, all gastropods, but 3593 marine species and a few (89) that inhabit freshwater; these last include, as well as gastropods, other members of the phylum such as bivalves and cephalopods. As we have seen with other groups, our terrestrial fauna is highly diverse at a species level and there

left **Kauri snail, Warkworth, Auckland, June 1980. Crown Copyright, Department of Conservation: Te Papa Atawhai, 2005.**

left **Leopard slug (*Limax maximus*) feeding on fungi; an European introduction. Photograph: Simon Francicevic.**

are also many different species co-existing with each other; one study in 1999 recorded 36 charopid and 19 punctid species from single localities near East Cape, very impressive even on a world standard. In the forest, herbivorous native snails (usually pretty tiny, although some slugs can exceed 10 cm) feed mainly on organic debris. Conversely, some of the larger snails, such as *Paryphanta* species (the kauri snails, endemic to the north) and *Powelliphanta* species (from the central North Island south, especially in Buller and Nelson), are nocturnal, carnivorous and feed on worms, insect larvae and other soft-bodied invertebrates with occasional recourse to fungi; some *Rhytida* species prey on their own young as well as on other snails. The *Wainuia* snails can even extend their mouthparts fast enough to catch jumping forest-dwelling amphipods. The *Paryphanta* and *Wainuia* genera may date back to the late Palaeozoic or early Mesozoic; however, the common garden snail is a European import, *Helix aspersa*.

Notable also is the very diverse range of flax snails (*Placostylus* species), mostly restricted to the Three Kings Islands and Te Paki areas, although *P.* (*Maoristylus*) *hongii* lives at Whangaruru North Head and the Whangarei Heads as well as on islands off Northland's east coast as far down as Great Barrier; they used to be much more widespread in Northland than they are today. The Three Kings Islands also provide a home for thin-shelled *Delos* species snails of the family Rhytididae; the similarly thin-shelled *Delouagapia cordelia* lives on mainland Northland.

Presumably, not only have these snails had their range restricted due to predation pressure from introduced animals as well as habitat clearance, but we have completely lost others to extinction.

New Zealand has native slugs, the Athoracophoridae, which can be distinguished by the leaf-vein pattern on their dorsal surface (leaf-veined slugs or putoko). It should be noted that the natives are not the ones that damage garden plants — the latter are introduced species!

PHYLUM NEMERTEA

A few ribbon worms are either fully terrestrial or live in freshwater — these have a very high rate of endemism, unlike their marine counterparts (by now a familiar story).

VERTEBRATES OF THE NORTH

All chordates (phylum Chordata) have, at some point in their life, a notochord — a somewhat flexible rod running along the length of the body. The most primitive retain a notochord lifelong, e.g. the lancelet; in higher chordates, it is typically replaced or broken up in adults by a vertebral column, although a thin, continuous notochord persists in geckos and tuatara. Hence, all vertebrates (subphylum Vertebrata) are chordates, including humans; and vertebrates comprise the vast majority of chordate species.

FRESHWATER FISH

Our freshwater fish are dealt with in Chapter 8, living as they do in water rather than on land.

AMPHIBIANS

New Zealand has its own unique native frogs, members of the class Amphibia and order Anura, with primitive features not found in frogs elsewhere (although they are highly evolved in their own way). All are rare, and all are members of the genus *Leiopelma*. Two species live in northern New Zealand (Hochstetter's frog *L. hochstetteri* and Archey's frog *L. archeyi*); fossils of another (the Waitomo frog *L. waitomoensis*), now extinct, have also been found in and around the Waitomo District

below **Archey's (left) and Hochstetter's (right) frogs, photographed together on the Coromandel Peninsula in 1973. Crown Copyright, Department of Conservation: Te Papa Atawhai, 2005.**

as well as in Hawke's Bay and the Wairarapa. *Leiopelma* are unusual in that they do not go through an external free-living tadpole stage, although they do develop into tiny tadpoles, then froglets, inside the eggs which are laid in the environment. Hochstetter's frog eggs do hatch into a more tadpole-like form than Archey's frog, with their forelegs still buried under a membrane and a longer tail, but rather than living freely in water, they merely remain in moist depressions in the soil until they develop into froglets.

Both our frogs may be found in the high forests of the Coromandel, although they used to be more widespread. Hochstetter's frogs also range from about Whangarei to East Cape as well as on Great Barrier Island, living beside streams; they used once to live further south but are now extinct beyond this range. Both are small (between about 28 and 38 mm) and brownish, with Archey's being smaller than the others and slightly mottled with green. Recently, Archey's frogs have been successfully bred at Auckland Zoo.

Another 'living fossil', our *Leiopelma* frogs are virtually identical to their ancestors in the Jurassic, complete with tail-wagging muscles (although no tail), no ear-drums or vocal sacs, and minimal or no webbing between their toes and hind feet. Hence they are often described as 'primitive' — but as they do not have tadpoles they do not need water in which to spawn and can instead exploit a wider range of forest environments than 'more advanced' frogs. Indeed, only Hochstetter's frog is found near water and even it has only minimal webbing between its toes; Archey's has none. However, they all need moisture and will die if dried out by wind and sun.

More common than the native frogs, however, are three introduced species, all Australians, that have established themselves here (others were also introduced but failed to maintain self-supporting populations). The green and golden bell frog (*Litoria aurea*) has only been able to survive in northern New Zealand, whereas the southern bell frog (*L. raniformis*) inhabits most of the country. Conversely, the brown tree frog (*Litoria ewingii)* is common in the South Island and the southern North Island but has only occasionally been reported in northern New Zealand, probably through deliberate releases.

Unfortunately, new threats emerge all the time. Chytridiomycosis (caused by *Batrachochytrium dendrobatidis*, a non-hyphal zoosporic fungus) is a recently recognised threat to amphibians worldwide and has had a significant effect on our unique native frogs.

REPTILES

New Zealand is well known for its birds, or avifauna, and rightly so — but our reptiles (members of the class Reptilia, in New Zealand represented by geckos, skinks and the tuatara) also comprise a very diverse and numerous group, especially considering our relatively small size and temperate climate; it is claimed that we have more species than any other temperate climate. Many have unusual features that make them of particular interest to science and all are now protected. Like birds, amphibians and invertebrates, many must have become extinct with the arrival of humans, although we know little about those extinctions; many more have been restricted to a very limited range and are much less common than once they were. Thus, the important roles they must have filled in the ecosystem, such as seed dispersal, will have been negatively affected by their decline.

Although some reptiles, such as the tuatara, may have been here all along, surviving the Oligocene immersion, many probably arrived more recently; some are even human introductions. Reptiles disperse more

easily to islands than mammals because they and their eggs are more resistant to the drying effects of wind and salt and can therefore raft between landmasses.

Most of our reptiles give birth to live young, the egg having hatched within their mother (ovoviviparous). This is thought to be an adaptation to a colder climate, where keeping the offspring 'on board' in a warm, controlled environment improves their survival in a hostile world. In contrast, worldwide most skinks are oviparous (lay eggs). Our reptiles also tend to have a long lifespan, are slow to mature and have low fertility, so-called K-selection; this seems to be an advantage in a stable environment (but not in one that is changing) and is common in our fauna, as previously discussed.

WHERE TO FIND NATIVE LIZARDS

Lizard names are confusing; the scientific names have recently been changed, with *Hoplodactylus* being split into new genera, *Cyclodina* skinks being subsumed into *Oligosoma*, multiple common names for the same species, and new species being identified but not as yet assigned a scientific name. This is a reflection of the fact that herpetology in New Zealand is a growing and exciting field with more and more being discovered about our lizards, such that we should consider New Zealand not just a land of interesting and unique birds but also a land of equally interesting and diverse reptiles (as well as amphibians and invertebrates).

Lizards can be found in almost all terrestrial environments; forests contain a wide range of habitats and the North Island also has a range of litter-dwelling skinks. Shrub- and vinelands are favourites of green geckos (*Naultinus elegans*) and, together with rocky areas, also of *Woodworthia* geckos and *Oligosoma* skinks. Divaricating shrubs are probably prime sites since lizards can sunbask in safety and forage for berries that birds and mammals can't get at. Some small-leaved coprosmas, such as mingimingi (*C. propinqua*), seem to have evolved to favour reptiles for seed propagation, with features such as non-red seeds (New Zealand birds are thought to favour red) and berries tucked away so that they can only be got at by small animals. An additional lizard defence is that they can shed their tail, leaving it behind as a distraction when threatened by a predator; they also shed their skin, although that is more a natural function than a defence!

Many lizards find the perfect retreat site in hard-to-get-at places in rocky areas such as crevices, boulder fields and scree. Quite a few lizards live by the sea, including the genera *Hoplodactylus*, *Woodworthia* and *Oligosoma*. Indeed, several *Oligosoma* skinks are shore specialists, including the moko (*Oligosoma moco*), shore skink and tatahi skink (both *O. smithii* although the tatahi is the type in western Northland, the Three Kings Islands and Te Paki) which live within a few hundred metres of the shore. The egg-laying, diving or Suter's skink (*O. suteri*) and the Fiordland skink (*O. acrinasum*) like boulder beaches and creviced rock platforms within the splash zone. *Oligosoma* skinks also may be found in grasslands, herbfields and open country as can, if there are enough rocks for them, *Woodworthia* geckos.

In our region, a major centre of diversity is the Aupouri Peninsula. The Three Kings and Poor Knights islands also support important local endemics (they have their own species of *Dactylocnemis* gecko) and even the tiny Mokohinau Islands have their own species (*D.* sp. 'Mokohinau gecko'). In general, lizard diversity tends to decline as one travels towards the Central Plateau.

Lizards are, of course, also more diverse on our offshore islands, mainly because (as with most other species) these islands tend

to have been less modified and contain fewer introduced predators and competitors than the mainland; Middle Island, in the Mercury group, has never been invaded by mammals and contains 11 different reptile species including tuatara and Duvaucel's gecko (*Hoplodactylus duvaucelli*), as well as four species of seabird and the rare tusked weta. We are gradually releasing skinks on islands only recently made predator-free, such as the release in 2009 of shore skinks on Motuihe, to join the copper (*O. aeneum*) and moko skinks already there.

SKINKS

Skinks are, unfortunately, somewhat endangered in New Zealand. Worldwide, there are more than 1400 known species, mainly in the tropics and subtropics, but they are more cold-tolerant than many other lizards and are also present in Europe and the Americas as well as the likes of Africa, Asia and Australia. Whether they have been here all along or whether they drifted to our shores is unknown, but they have spread to inhabit every main island, including the Three Kings, as well as every habitat. Once upon a time, the skink population of New Zealand must have been extremely dense, but mammalian predators have, unfortunately, put paid to that.

Skinks are characterised, as opposed to geckos, by a smooth, shiny skin with overlapping scales, a narrow head, smooth, narrow toes and small round pupils with movable lids. Most skinks also live on the ground as opposed to in trees, and their skin sloughs off in pieces rather than all at once. However, the striped skink (*Oligosoma striatum*), found in northern New Zealand (Rotorua, Kaipara, King Country and both Great Barrier and Little Barrier islands) and Taranaki seems to prefer an arboreal existence. Unfortunately this unique skink is also very rare, with only 120 specimens ever

top **Mokohinau skink. Crown Copyright, Department of Conservation: Te Papa Atawhai, 2005.**

bottom **Chevron skink, Great Barrier Island. Crown Copyright, Department of Conservation: Te Papa Atawhai, 2005.**

having been found; currently it is known from around 40 widely scattered sites throughout the central and upper North Island in lowland forest and farmland.

In New Zealand there is just the one genus of native skinks, *Oligosoma*, with 33 extant members; six *Oligosoma* species used to be in the genus *Cyclodina*, prior to a recent taxonomic revision which rendered *Cyclodina* obsolete. Unfortunately our largest skink, *O. northlandi*, must now be presumed extinct but a new skink species may have recently been discovered at Bream Head, near Whangarei.

In the main, skinks are carnivores, eating invertebrates and occasionally each other or carrion, but they also eat fruits and vegetative material, especially those that grow on divaricating shrubs or in dense tangles that birds can't reach.

The only native skink that lays eggs is also the only nocturnal *Oligosoma* species (the egg-laying skink); the rest are diurnal. It lives on the beaches of our northeast islands such as the Aldermen Islands and on some parts of the adjacent mainland, laying its eggs under boulders, in crevices under rocks and under seaweed, to remain protected from desiccation.

The rainbow skink (*Lampropholis delicata*), introduced accidentally into Auckland from Australia in the 1960s, probably in cargo, and now well established and found as far south as Whakatane, also lays eggs. It is our only introduced reptile and appears to have naturalised in the wild. It is often found in urban gardens and industrial sites and it competes with native skinks, to the latter's detriment.

The rarest and longest skink in New Zealand (143 mm from snout to vent) is also in the north — Great Barrier's chevron skink (*O. homalonotum*); a few have also been found on Little Barrier Island, but there have ever only been 100 sightings. As a result there are gaps in our knowledge about them, but juveniles at least like the damp banks of streams and they seem to take cover in pools of water, which is unusual for a skink; the environment that the adults prefer is unknown. Luckily there are no Norway rats on Great Barrier Island, since they also like damp places.

Skinks can let their tail go, which will keep twitching as the rest of the skink departs, hopefully distracting a predator sufficiently to allow the skink to escape. In the past, skinks were predated by natives such as tuatara, weka and takahe, but nowadays the predator is more likely to be a mammal, the worst culprit being the rat.

As a result of predation, competition and habitat loss, more than half of our skinks have disappeared from the mainland; island sanctuaries such as the Mercury Islands have been the recipient of translocations of the rare Whitaker's (*O. whitakeri*) and robust (*O. alani*) skinks as a conservation measure.

GECKOS

Geckos, as opposed to skinks, have a velvety, loose-fitting skin, small granular scales, a wide head and wide toes with tiny hairs to aid climbing, and have large eyes with oval pupils. Instead of eyelids they have a clear scale over their eyes that they keep clean by licking (it does not need to be kept moist). Again, they give birth to live young (all other species in the world give birth to eggs except for one in New Caledonia), and some common geckos have been known to live for over 40 years (vs a 2-year lifespan for geckos in the tropics), maturing at 7 or 8 years. In the common gecko species *Woodworthia* (ex-*Hoplodactylus*) *maculatus*, specimens that live at altitude where it is colder have pregnancies that last 14 months, vs 3–5 months in warmer areas; the pregnancy is put on hold over winter.

Like skinks, geckos can also lose their tails,

and they generally eat invertebrates although can also eat nectar, berries and carrion. They play a key role in pollination, carrying pollen and also eating and transferring fruit, but of course are in much shorter supply, especially on the mainland, than they once were due to predation and loss of habitat.

Geckos have a very interesting ability to climb up vertical walls and some, overseas, can even walk on ceilings, upside down. They do this because they have many tiny grooves on their feet, each with millions of tiny fibres which are themselves split 100–200 times at the ends. These nanofibres give the foot a massive surface area, generating enough van der Waals force to cling against gravity; when they want to let go, they just roll their toes out to reduce the contact area.

Our geckos are unusual in that they often come out during the day; in fact, *Naultinus* is primarily diurnal. In the rest of the world, they are usually strictly nocturnal.

There are two sorts of gecko — the green (*Naultinus*) and the brown (*Dactylocnemis*, *Hoplodactylus*, *Mokopirirakau*, *Toropuku*, *Tukutuku* and *Woodworthia*); brown geckos used to be all lumped together as *Hoplodactylus* but have now been split up into six different genera.

Green geckos

Green (*Naultinus*) geckos, of which there are at least nine species, have a fixed green colouration, live in trees (are arboreal) and are active during the day (are diurnal). The species found in northern New Zealand include the yellow-lipped gecko (*N.* sp. 'North Cape green gecko') of the upper Aupouri Peninsula, which inhabits kanuka and manuka shrublands, and Gray's gecko (or Northland green gecko, *N. grayi*), living in the area from the Bay of Islands to the Hauhora Harbour in forest, scrub and scrubby wetlands. Also ranging from the Bay of Islands south, but this time further south to Wanganui (although excluding Gisborne

District), is the elegant gecko (or Auckland green gecko, *N. elegans*). It also lives on some islands, including Great Barrier, Little Barrier and Waiheke, inhabiting forest and shrublands. The barking or Wellington gecko (*N. punctatus*) of the North Island's east coast as well as further south in the North Island occupies the same habitat in that region.

Brown geckos

There are at least 33 species of brown gecko, which can alter the tone of their colour (e.g. light brown to dark brown); most of these are active at night and live on the ground, in scrub and bush as well as rocky crevices. Most can also be found sunbasking during the day.

The matua or common gecko (*Woodworthia maculata*) is the most widespread gecko below the treeline, except in the Waikato. It is especially common near the coast, although it is missing from the Poor Knights, Mokohinau and Three Kings islands.

Also widespread, with the exception of the Gisborne District and the very far north, is the notoriously timid Pacific gecko (*Dactylocnemis pacificus*); it is particularly abundant on offshore islands and lives from the forest right down to driftwood and rocks above the high-tide mark.

We once used to have the largest gecko in the world, *Hoplodactylus delcourti* or kawekaweau, the last verified live sighting of which was in 1870 near Whakatane; it was up to 2 feet (60 cm) long. Duvaucel's gecko (*H. duvaucelii*) is currently the largest gecko in northern New Zealand (it reaches up to 200–320 mm in total length, and one specimen weighed 118 g), confined in that area to islands offshore from eastern Northland, probably due to rat predation. (It can also be found on islands in the Marlborough Sounds and has recently been introduced to Wellington's Mana Island). Although mostly nocturnal, it may be active in the late afternoon.

Forest geckos of the species *Mokopirirakau granulatus* range from north of Hamilton up to the base of the Aupouri Peninsula; they are also often active during the day (especially late afternoon) as well as at night, and are both arboreal or, above the treeline, ground-dwelling. Like Duvaucel's gecko and many other plants and animals, they are also found

opposite **Auckland green gecko. Auckland Zoo, Auckland.**

left **Duvaucel's gecko. Crown Copyright, Department of Conservation: Te Papa Atawhai, 2005.**

in the climatically clement and geologically stable northwestern part of the South Island but not in the rest of the North Island.

Another arboreal gecko is the striped gecko (*Toropuku stephensi*) which is found in the northern Coromandel (and, again, on Stephens and Maud islands in the Marlborough Sounds); it is particularly partial to pohuehue, kanuka and manuka. Living a very similar lifestyle but further north, on the Aupouri and Karikari peninsulas, is the matapia gecko (*Dactylocnemis* sp. 'Matapia'); although on the mainland it inhabits manuka and kanuka scrub, on offshore islands it can also be found in pasture.

Dactylocnemis species 'North Cape Pacific gecko' occurs right up the top of the Aupouri Peninsula, in manuka and kanuka scrub, kauri forest, clay crevices and boulders above the splash zone. There are also three island-dwelling *Dactylocnemis* species which, although very similar — all enjoying sunbasking and living both arboreal and terrestrial lifestyles from the forest down to the upper shoreline — have all adapted differently to their environments. The population of Poor Knights gecko (*D.* sp. 'Poor Knights gecko') on Sugarloaf Rock has become diurnal and eats fish regurgitated by nesting seabirds; the very large Three Kings Islands gecko (*D.* sp. 'Three Kings gecko'), our second-largest surviving gecko on those islands, is also mostly diurnal; the Mokohinau gecko (*D.* sp. 'Mokohinau gecko') is not diurnal.

There are many other regional variations within the same lizard species, for instance, the common geckos (*Woodworthia maculata*) of the Hauraki Gulf, which range from Whangarei Heads to Port Jackson in the northern Coromandel, are smaller (around 65 mm snout to vent) than those of Cuvier Island, the Bay of Plenty and Wairarapa (75 mm); they also typically inhabit boulder beaches rather than forest and their colouration is also different. Both differ yet again from other variants of the same species even further south.

TUATARA

The final reptile, and surely the most iconic, of our region is the tuatara (ours are *Spenodon punctatus*), the only member of the ancient sphenodont reptiles which evolved around 220 Ma; they are, in fact, the only extant member of the order Rhynchocephalia. Tuatara survive in northern New Zealand on our eastern offshore islands, the only other areas until recently being certain islands of Cook Strait as well as in zoos and museums. Some offshore islands, like Little Barrier and the smaller Mercury islands, have always been a stronghold of tuatara; they have been re-introduced to others following pest eradication, such as Tiritiri Matangi and Motuihe islands. On the mainland, they have now been re-introduced in the fenced Maungatautari Ecological Island in the Waikato as well as to Wellington's Zealandia sanctuary and, in the South Island, to the Orokonui Sanctuary just north of Dunedin. The last is of particular interest as tuatara transported there are from much further north and the temperature at which tuatara eggs are incubated determines the sex of the offspring; when the eggs are incubated at cold temperatures, the offspring are female, but when warm they turn out to be males. We await the results of this experiment with interest.

Tuatara have a phylogenetically very ancient third eye on the top of their head, with its own optic nerve and retina, although it does not open onto the skin surface; it is connected to the pineal gland which is responsible for detecting day and night and adjusting the circadian rhythm. The pineal gland survives in other vertebrate species, including our own, but its eye does

not; instead it receives input relayed via the hypothalamus from the other two eyes. In this and other respects (such as their skeletal structure), the tuatara may be considered to be a living fossil, retaining a structure now lost in other species; and indeed they have survived about 200 million years without significant change.

Tuatara eat invertebrates, chicks and eggs and live in the burrows of seabirds such as prions, petrels and shearwaters. They may possibly live for more than 100 years, only reaching full size between 25 and 35 years of age. They lay their eggs 8–9 months after mating and then the eggs do not hatch for another 11–16 months.

Reptiles are more common in more-tropical regions, but of course tuatara have survived numerous Pleistocene glacials as well as our generally more temperate climate; they perform best at temperatures between 16°C and 21°C, and can even operate down to 7°C, an extremely low temperature for a reptile.

above **Tuatara. Auckland Zoo, Auckland.**

BIRDS OF THE FOREST

Once New Zealand was veritably the land of birds (class Aves), but since the arrival of humans and their assorted pests their numbers have been decimated and many species are now extinct; flightless birds are particularly vulnerable and New Zealand was well endowed with those.

Birds are vital to healthy forest ecosystems; for instance, they transport seeds and are a source of grazing pressure. The reverse is also true. Virgin forests, such as the giant podocarps of mixed ages in the Pureora Forest Park, now sadly much less extensive than they were, are very important for birdlife, including the hole-nesting native parrots kaka and both red- and yellow-crowned kakariki. As a result, the falcon, the whio (blue duck) and the largest remaining North Island kokako populations are also found here. Our native

birdlife has been seriously affected by not just introduced predators but also loss of habitat; often, of course, the two combine to further imperil vulnerable species.

Native forest has been less penetrated by introduced bird species than many habitats; most prefer open country, but exotic forests in particular are congenial to thrushes, finches, larks and blackbirds.

Native birds tend to breed in spring and summer and most are monogamous, although there are exceptions, such as, on occasion, the hihi (stitchbird).

FLIGHTLESS BIRDS

The northern brown kiwi (*Apteryx mantelli*) is northern New Zealand's mainland representative of the national bird. It lives not only in forest but also in scrub and tussock, and four different 'races' may be found — the Northland, Coromandel, eastern (Bay of Plenty, Te Urewera and Hawke's Bay) and western (Waikato, Taranaki, Tongariro and Whanganui) races. Northland north of Whangarei and Dargaville is a particular stronghold for this bird, although its mainland population is declining in many places and some local populations have become extinct since the 1970s. Motuora Island in the Hauraki Gulf has been established as a breeding centre to allow juveniles to grow up and become large enough to fend off predators. The Moehau Kiwi Sanctuary at the tip of the Coromandel is our largest kiwi sanctuary but there are several other mainland kiwi protection and support programmes, such as at the Ohope Scenic Reserve in the eastern Bay of Plenty. Tiritiri Matangi, Hen, Red Mercury and Motuihe islands are sanctuaries for the little spotted kiwi (*A. owenii*). Both species are nocturnal, use their long beak to forage on the forest floor and have a well-developed sense of smell — in more than one sense, they act much more like mammals than birds.

North Island weka (*Gallirallus australis greyi*), another terrestrial flightless rail, is inquisitive, curious and a predator of small animals, but is now only found in northern New Zealand in a few locations. One such location, perhaps surprisingly, is the area around Kawakawa Bay, on the mainland and very close to Auckland; the locals take a special interest in their own rare bird. Finally, the South Island takahe (*Porphyrio hochstetteri*), the southern relative of the now extinct North Island takahe (*P. mantelli*), has been introduced and lives in grasslands and forest margins on pest-free Tiritiri Matangi and Motutapu islands and in the Maungatautari Ecological Sanctuary; plans are afoot to re-introduce it elsewhere in similar sanctuaries. New Zealand's flightless parrot, kakapo (*Strigops habroptilus*), was locally extinct but has been re-introduced to Little Barrier Island.

below **Greg, one of Tiritiri Matangi Island's favourite takahe, died on 12 August 2012, aged 19 years. Auckland.**

above **A kaka, *Nestor meridionalis*. Crown Copyright, Department of Conservation: Te Papa Atawhai, 2005.**

THE LARGER FOREST BIRDS

The larger bush birds tend to be the berry-eaters, including the native wood pigeon, also known as kereru, kukupu, and kuku (*Hemiphaga novaeseelandiae*) which, although protected, is still often shot illegally. Kereru today are particularly vital for the dispersal of forest seeds, as they are now the only birds, following the demise of species such as the moa, that can carry the largest fruit (they are probably the only carriers for taraire, karaka, miro and tawa fruits that are more than 1 cm in diameter). Since they congregate to feed but then disperse widely, they are also important dispersers of smaller seeds such as rimu, nikau, matai and pigeonwood. They do not digest the seeds; rather, the seeds are abraded in the bird's gut with the nutritious fleshy pulp being stripped away as an essential part of the bird's diet; this process promotes germination of the seed. Like many natives, kereru are long-lived and have but few offspring; their numbers are declining, perhaps more precipitously than is obvious owing to the longevity of the adults, due to ongoing illegal hunting and predation by stoats (of adult birds) and rats (of eggs).

Similar in size is a parrot, the kaka (*Nestor meridionalis*; the division into North and South Island subspecies has not been supported by genetic data), which prefers large tracts of kauri and podocarp forest but is now reduced to a few areas in the Coromandel and central North Island forests as well as on predator-free islands, particularly Little Barrier; it can sometimes be seen visiting the nearby mainland including, on occasion, Auckland city. Kaka have a varied diet including fruit, such as matai and miro berries, as well as kowhai and rata nectar, honeydew from beech, bark, leaves and insect grubs, dug out from the ground or bark. Old and dead trees are an important source of food for kaka, as they dig insects out of the trees and these ones, with their soft, rotting wood, are easily penetrated as opposed to the hard bark of live trees.

left **A common native passerine, the tui. Omaha, Auckland.**

THE PASSERINES

Slightly smaller forest birds are the honey-eating passerines, a mainly Australian group of birds which include tui (*Prosthemadera novaeseelandiae*), bellbirds (*Anthornis melanura*) and, now confined to Little Barrier Island, Tiritiri Matangi and predator-controlled areas on the mainland, the hihi/stitchbird (*Notiomystis cincta*). Tui are common and, as a result, extremely important in the spread of native plant seeds. The bellbird was exterminated from the mainland north of Auckland, probably by disease, in the 19th century although it survived on offshore islands including Little Barrier, the Poor Knights and the Three Kings, and is re-introducing itself to the mainland sanctuaries of Tawharanui and Shakespear Regional parks. Recently it has been re-introduced to other areas, including even the Hamilton Gardens.

Two native species of parakeet (kakariki) are also found in northern New Zealand, the red-crowned (*Cyanoramphus novaezelandiae*), now rare on the mainland, and the yellow-crowned (*C. auriceps*). Their unwanted introduced Australian relative, the eastern rosella (*Platycercus eximius*), now occurs in the bush north of the Waikato.

The North Island kokako (*Callaeas cinera wilsoni*), our largest native passerine, a type of wattlebird and now one of our endangered species, can now be found only in more inaccessible forests including Pureora Forest Park, the Hunua Ranges, Te Urewera and, in Northland, the Puketi Forest and Mapara Reserve, as well as offshore sanctuaries including Tiritiri Matangi and Little Barrier islands; it is also being re-introduced to Ark in the Park, an area of intensive predator control in the Waitakere Ranges west of Auckland. It is a poor flier, flitting through the forest canopy eating young leaves and berries as well as small insects found in lichens and mosses on trees. At least it has done better than its South Island counterpart, which became extinct during European times. Another large passerine is the North Island saddleback (*Philesturnus carunculatus rufusater*); although it nests in trees and fern crowns, it is a very active ground-feeder and hence vulnerable to mammalian predation;

surviving on Hen and Little Barrier islands, it too has been re-introduced to the Hauraki Gulf nearer Auckland on Tiritiri Matangi, Motuihe, Rangitoto and Motutapu islands.

THE SMALL BIRDS

There are also many small bird inhabitants of our forest. The North Island rifleman (*Acanthisitta chloris granti*), the most common of New Zealand's wrens, is found in bush south of Auckland as well as on Tiritiri Matangi, Little Barrier and Great Barrier islands; the silvereye or waxeye (*Zosterops lateralis*) is much more common, even in suburban gardens, and rivals the rifleman for being New Zealand's smallest bird. It is classified as a native because it arrived here under its own steam, but was first recorded in New Zealand only in 1832 and began breeding by about 1856. It has flourished probably because it has not been here long enough to gain disadvantageous adaptations with respect to the changed environment after human settlement! We also have nine species of flycatchers and warblers, smaller passerines: the pied fantail (*Rhipidura fuliginosa*), tomtit (*Petroica macrocephala*) and grey warbler (*Gerygone igata*) are all widespread and are also found in exotic forests, scrub and even populated areas in the case of the grey warbler. The whitehead (*Mohoua albicilla*) is unfortunately confined on the mainland to native and exotic forests south of Hamilton but is present on Little Barrier, Tiritiri Matangi and Mokoia islands (the last being in the middle of freshwater Lake Rotorua); and the North Island robin (*Petroica longipes*) has for the most part retreated to Te Urewera, Mamaku Ranges and forested ranges further south, although re-introduced populations can be found on predator-free islands and in areas, such as Auckland's Hunua Ranges, where mammalian predators are controlled to very low levels.

above **North Island robin. Billygoat Basin, Coromandel Forest Park, Thames-Coromandel District.**

AVIAN PREDATORS

The morepork (*Ninox novaeseelandiae*) is also mostly found in bush, although it can be heard anywhere where there are sufficient trees or shrubs for cover, including in urban areas; it is our one remaining native nocturnal avian predator, feeding on small birds, insects, lizards, mice and the Polynesian rat (kiore); the little owl (*Athene noctua*) is established in the South Island but hasn't reached the North, at least as yet. Diurnal avian hunters include the endemic New Zealand falcon (*Falco novaeseelandiae*), common mainly in forest from the Waikato south, as well as the Australasian or swamp harrier (*Circus approximans*); the latter prefers hunting in open country, breeding in scrub, raupo and swamps and is perhaps one of the very

above **A swamp harrier patrols the skies above Waikato farmland (north of Hamilton). Waikato District.**

few beneficiaries of the more open country mankind has created in New Zealand, although it may also be a recent arrival. These hunters may be joined by two occasional vagrants from Australia, the Nankeen kestrel (*Falco cenchroides*) and the barn owl (*Tyto alba*).

PASSING VISITORS — THE CUCKOOS

Two species of cuckoo also visit our shores in the summer, wintering in the Pacific Islands; birds mainly of the bush, the shining cuckoo (*Chrysococcyx lucidus*) also favours willows and the long-tailed cuckoo (*Eudynamys taitensis*), often heard at night, has spread to exotic plantations.

INTRODUCED BIRDS

Birds such as the myna (*Acridotheres tristis*), house sparrow (*Passer domesticus*), various finches, the blackbird (*Turdus merula*) and eastern rosella are among the most common birds encountered in everyday life in northern New Zealand; none of these are native but all have acclimatised well and are frequently encountered, especially in modified environments such as farmland and urban areas, often at the expense of native birds.

MAMMALS

NATIVE BATS

There are two species of native bat in our forests, our only native terrestrial representatives of class Mammalia. The lesser short-tailed bat (*Mystacina tuberculata*), however, acts in a very un-pteropine (un-bat-like) fashion, foraging on the forest floor for all the world like a tiny pig, folding its wings in a unique fashion for protection as it does so. This enables them to supplement their diet with nectar, fruit and terrestrial insects; they even scavenge carcasses. This niche is of course similar to that exploited by kiwi but occupied overseas by terrestrial mammals. Numbers of these bats would seem secure but they are rarely encountered as they usually emerge well after midnight, roosting in tree cavities in old-growth forest during the day. They are unique to New Zealand and do not have close relatives elsewhere, but there used to be a greater short-tailed bat (*M. robusta*) which met the usual rat-induced fate of many of New Zealand's recently extinct animals. The lesser short-tailed bat may be important as the only native pollinator of the endangered parasitic dactylanthus; it is also the only known host of the New Zealand batfly (*Mystacinobia zelandica*).

Long-tailed bats (*Chalinolobus tuberculatus*) are one of the 17 species of the Australian *Chalinolobus* genus and by far more likely to be encountered, since they emerge after dusk to fly over clearings and rivers in pursuit of large nocturnal airborne insects such as moths and do not require

old-growth trees to roost in. They have smaller ears and longer tails than the short-tailed bats; they are also more widespread, having been recorded outside the range of short-tailed bats, for instance in the Waikato and Raukumara Range. However, despite being more widespread and more agile on the wing, their population may be declining substantially. They hibernate during the winter months in hollow trees.

INTRODUCED MAMMALS

Of all the various classes of animal, none was once so obviously absent (except for the bats and marine mammals which hauled out on coastal sites and occasionally ventured a little further upstream) as mammals; but they are now so ubiquitous that one, the sheep, is considered a symbol of our country — perhaps to be superseded in this category by the cow?

Introduced mammals compete with and eat the native flora and fauna, eat native plant seedlings and occupy land that would otherwise be a habitat for native ecosystems; but some, sheep and cattle in particular but also pigs, deer, goats and other mammals, are staples of our economy. Other animals, particularly cats and dogs, are beloved pets that are unlikely to ever be actively exterminated from our country — although they have been, with remarkable results, from various offshore islands.

The history and threat posed by these introduced mammals is covered more extensively in Chapter 4.

A NOTE ON TAXONOMY: NATIVE, ENDEMIC AND EXOTIC

Taxonomy, in the biological sense, refers to the science of describing and classifying organisms, grouping them into progressively tighter groups according to similar characteristics. It is constantly being refined, particularly with modern genetic analysis which sometimes throws superficially dissimilar organisms into the same group, in order to base the classification on evolutionary relationships.

It is a hierarchical classification, with different 'ranks' which can be remembered using the mnemonic 'Do Kings Play Chess On Fine Glass Sets?'. The first letter of each of these words stands for the ranks which are, in order from most to least inclusive: domain, kingdom, phylum, class, order, family, genus, species.

'Native' refers to organisms that have arrived here under their own steam; 'endemic' means those organisms which are both native and exist only here. Conversely, 'exotic' (also 'introduced' or 'adventive') organisms have only reached here with assistance; 'naturalised' organisms are those exotic organisms that have become sufficiently well established here that they can sustain themselves in the wild. One can also refer to the various taxonomic ranks ('taxa') as being native or endemic; for instance, kiwis (of which there are more than one species) belong to class Aves and genus *Apteryx*. Class Aves, to which all birds belong, is native but not endemic to New Zealand while the genus *Apteryx* is both native and endemic.

CHAPTER EIGHT:

THE FRESH-WATER ENVIRONMENT

INTRODUCTION

Northern New Zealand is blessed with an abundant rainfall and surrounded by sea. As a result, we have almost every type of wetland imaginable.

The term 'wetland' can be used to describe any environment that is either permanently or transiently wet, not only freshwater lakes, rivers, swamps or bogs but also saltwater estuaries and even the ocean; this chapter will be limited to freshwater environments only, and I shall use the term wetland to refer to these freshwater environments that lack open water, as distinct from lakes and rivers.

All our freshwater environments have been affected to varying degrees by the recent arrival of humanity, with removal of the vegetation around them, drainage and modification for agriculture and other purposes, the introduction of aggressive overseas competitors such as crack willow (*Salix fragilis*), and increased sedimentation from land clearance. Some rivers have been converted into lakes by man (most notably the hydro lakes of the Waikato River) and new waterways have been formed, in the form of drains, diversions and canals. Most affected have been our palustrine ('marshy') wetlands, 90% of which (on a national scale) are now gone, mainly as a result of drainage for agriculture.

LAKE AND WETLAND FORMATION

There are several different ways in which lakes can form, although all require a hollow in the underlying ground without a route for the easy egress of water.

In northern New Zealand, lake types include:

- the small lakes typical of the west coast sand dunes which fill depressions created by the wind blowing sand into dunes and swales or blocking streams

- those formed from a river being blocked by landslides. These have a branching (dendritiform) shape that reflects the previous riverine nature, very similar to the drowned river valleys (rias) of our harbours. Our second largest lake, Waikaremoana, was created when a landslide cut off its outflow; an even larger landslide resulted in nearby Lake Waikareiti. The latter has filled significantly with alluvium and is gradually disappearing

- lakes such as Lake Omapere and Auckland's Western Springs that have been cut off by lava flows from their former outlets. Auckland also had a collection of 'maar' lakes filling the centre of tuff rings (e.g. Lake Pupuke); many have subsequently been breached by the sea at one point so that they are no longer lakes (e.g. Orakei and Panmure basins)

- some lakes and wetlands formed in depressions

top **A combination of freshwater environments — river, marsh and dune lakes. Te Paki, Far North District.**

middle **The water's point of view; a classic North Island bush-shrouded stream. Anaura Bay, Gisborne District.**

bottom **The landslide that cut off Lake Waikaremoana. Since this lake has been used for hydroelectric power generation, holes within this landslide have been plugged and the overflow directed to drive the turbines. Wairoa District.**

left by a geologically subsiding landscape, such as those (e.g. Rotorua and Taupo) filling the collapsed volcanic caldera of the Taupo Volcanic Zone (TVZ) as well as the Kopuatai Peat Dome of the Hauraki Plains, which occupies a subsiding landscape derived from tectonic downfaulting. The caldera lakes have overflowed at the lowest point in their rim to drain out as a river

- river-formed (fluviatile) lakes. One form, 'lateral lakes', are particularly common in the subdued Waikato basins, forming where rivers have deposited sediment in the form of levees along their banks which have in turn cut off the drainage from more-peripheral areas

- manmade lakes formed by damming rivers, for instance the hydroelectric dams along the Waikato River and Auckland's water supply dams in the Waitakere and Hunua ranges

- lakes created when a spit forms across an embayment (barrier-bar lakes). There are many small examples of this in the north, such as Lake Rotongaio, separated from Lake Taupo by a sand bar.

Of course, some lakes are the product of more than one type of process. In general, lakes do not last long in geological terms; being non-tidal and small, their waves lack the erosive power of the sea and therefore over

top **One of our least-modified wetlands can be found inside the crater of Mayor Island, Western Bay of Plenty District.**

middle **An oxbow lake, formed when a meander became cut off from the main stream of the Whakatane River. This type of fluviatile lake is distinct from the lateral lakes described in the text. Whakatane District.**

bottom **Lake Wainamu, in Auckland's Waitakere Ranges, was formed by a sand dune which blocked a river valley.**

time, assuming no further disturbances, they become filled in with sediment, carried into them by rivers (fluvial inflow) as well as from direct run-off from the land. They gradually turn into wetlands and then dry land; there is often a wetland 'littoral fringe' surrounding any open water. Hence, the processes that form both lake and palustrine wetlands are similar.

The vast majority of our lakes were not present 50,000 years ago (50 ka); those that were, predominantly in the TVZ, have subsequently been altered almost beyond recognition by further eruptions which created barriers such as volcanic hills or pumice dams which blocked off their outflows, causing their levels to rise before lowering again when an alternative egress was found at the next-lowest point in the contour of the land. For instance, Lakes Rotorua and Rotoiti once drained through the Tarawera River; when that outflow was blocked by the subsequent formation of the rhyolitic domes of Haroharo and Tarawera, their levels rose until the water found their current outflows; these outflows have then cut down, taking lake levels down with them. The youngest lake in this area is Lake Rotomahana, which was substantially altered into its current form in 1886 by the Tarawera eruption.

Most of the dune lakes and those that form in caldera are low in sediment since they have little fluvial inflow, and their levels may vary seasonally with precipitation and evaporation; Lake Taupo is an obvious exception and is being slowly filled with sediment at the delta of its largest tributary, the Tongariro River.

LAKES OF THE NORTH

LAKES WAIKAREMOANA AND WAIKAREITI

Surrounded by the natural beauty of Te Urewera, Lake Waikaremoana formed 2.2 ka when the Ngamoko Range slid into a gorge of the Waikaretaheke River, damming it in the vicinity of Kaitawa; the smaller Lake Waikareiti was formed in a similar way 11 ka by an even larger landslide. Lake Waikaremoana in particular has a dendritiform or branching appearance, when viewed from the air or on a map; this is because water accumulated in river valleys upstream of the landslides and drowned them; hence the lakes' various inlets follow the sinuous and branching pattern of these former river valleys. As sediment has gradually filled in these lakes, particularly evident in the older Lake Waikareiti, a hummocky landscape with wetlands and small lakes has formed; in the area of Kaipo

right **The natural beauty of the inlets of Lake Waikaremoana, Wairoa District.**

above **The dendritiform pattern of Lake Waikaremoana is visible in this satellite image. The landslide that blocked the original outlet to form the lake is at the lower right. The older and more infilled Lake Waikareiti and Kaipo Lagoon and associated bog are in the upper right. Te Urewera, Wairoa District. © 2014 Google TerraMetrics.**

Lagoon there once was another lake also associated with Waikareiti's landslide which has now mostly silted up. Lake Waikareiti is one of our most pristine lakes and remains free of introduced lakeweed.

THE CALDERA LAKES OF THE TAUPO VOLCANIC ZONE

The Rotorua lakes fill the caldera depressions left behind after our some of our largest volcanic eruptions; ignimbrite cliffs line the northeastern corner of Lake Rotorua itself.

Lake Taupo, our largest lake, exists at the intersection of the Hauraki Rift and the TVZ; its eastern arm occupies the tectonically subsiding trough of this rift zone, blocked in the north by pumice from Mounts Tauhara and Maroa that it has broken through at its Waikato River exit. The Western Bay of the lake, by contrast, occupies a more circular caldera. Volcanic events have changed the local topography many times in the past; not only have they reshaped the land but they have also changed the lake level. For instance, during the most recent eruption 1.8 ka Lake Taupo received huge volumes of pumice which blocked its outflow, causing the lake level to rise until it cut down through that dam again, in turn flooding the Waikato River with sediment and leaving debris as far as 220 km

left **Lake Rotorua: remnant kahikatea swamp forest may be seen in the right foreground and the rhyolitic dome of Mokoia Island is visible in the centre. Rotorua District.**

above **Our largest lake, Taupo, at dusk. The volcanoes of the central North Island, just south of this text's area, are visible rising up into the clouds. On the eastern slopes of Ruapehu is the Mangatoetoenui Glacier, the ultimate source of the Waikato River, our largest river. This glacier, once called the Waikato Glacier, is a principal source of the Tongariro River that flows into Lake Taupo, flowing out the other side as the Waikato River after spending an average of 10 years in the lake.**

downstream (and shaping the lakes of that region).

Islands within these lakes, such as Mokoia and Motutaiko, are rhyolitic domes that were extruded by volcanic activity.

THE RIVER-FORMED WAIKATO LAKES

As described in Chapter 1, the Waikato River has been running through the Hamilton Basin since about 22 ka, initially as a wandering braided river but then becoming trapped in its current fixed course as its sediment load decreased towards the close of the Pleistocene, due to the spread of forest in the river's headwaters and a reduction in volcanic activity around Taupo. Before becoming entrenched around 17 ka, it spread sediment across the Hamilton Basin in the form of a fan, blocking many small rivers and depositing sediment over the mouths of embayments in pre-existing hills to create basins, which subsequently filled with water (some also spontaneously drained). This process gave rise to the many small lakes of the Hamilton Basin, such as Hamilton Lake and Lake Rotomanuka. Some have also filled with peat to create peaty wetlands; larger peat wetlands were created in a similar manner to those in the Lower Waikato Basin, described below, when drainage of water was cut off by raised levees of sediment which accumulated along the various different 'paleochannels' through which the river ran just before it became entrenched in its current course.

After about 17 ka the Waikato River was

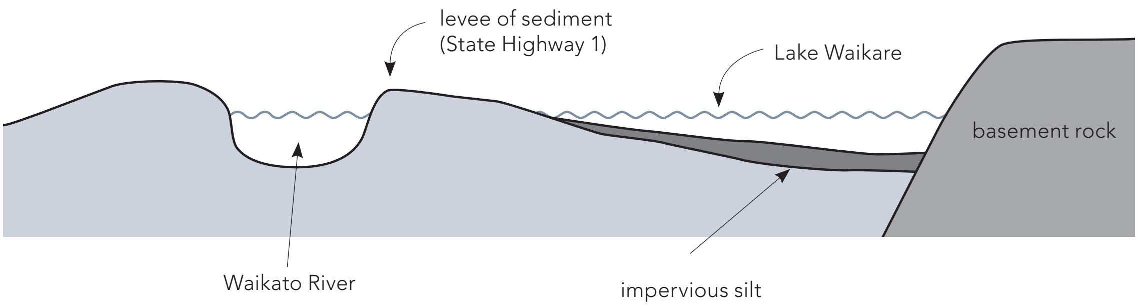
left **The scattered lakes of the Lower Waikato Basin; the Waikato River runs through the middle of the image but these lateral lakes are cut off from it. Brown freshwater wetlands are also visible surrounding some of the lakes. Waikato District.**

deep enough that it was able to transport its sediment into the Lower Waikato Basin, which extends from Huntly north to the bottom of the Bombay Hills. Then, around AD233, there was another massive eruption in Taupo; pumice and ash from this event blocked the outflow from Lake Taupo as well as other sections of the river further downstream. As these dams gave way, massive volumes of pumice and ash were swept downriver, creating levees adjacent to the channel and blocking drainage from the margin of the floodplain to form (or highly modify into their present form) the lateral lakes in the Lower Waikato Basin, such as Lake Waikare, and Whangamarino fen. The levees form useful corridors for our main roads and railways to traverse, between the river on one side and the lakes and wetlands on the other.

The Waikato lakes may be classified as either 'mineralised' or 'peat' lakes, the latter being associated with peat at some point in their history (many of the small lakes of the Hamilton Basin, including Hamilton Lake, are sandwiched between higher bedrock on one side and peat on the other). Before European settlement, the dominant water source for these lakes and their surrounding wetlands was precipitation, which carries with it no nutrients of its own, as they usually had neither inlet nor outlet and were therefore

Figure 1 **Formation of Lake Waikare and other lateral lakes (and fens) of the Lower Waikato Basin. The river deposits sediment as a levee along its banks, cutting off drainage from more-lateral areas. They become waterlogged and turn into lakes and fens.**

FORMATION OF LAKE WAIKARE, A LATERAL LAKE



relatively infertile. However, increased runoff from the surrounding farmed, nutrient-rich land into these lakes has led to an increase in nutrient levels to a point where they are now eutrophic (see below) and often silted up; the native life, adapted to low nutrient levels, has been replaced by introduced species. Some lakes have also been drained, reducing their level. In some instances the lakes have later been partially restored by being fenced off from stock, the drains being removed, and the surrounds planted with species such as rushes and kahikatea.

Mineralised lakes are more likely to have been modified; since peat lakes have boggy margins, they are often not farmed right to their margin but instead are surrounded by a zone of protective riparian vegetation. Mineralised lakes also often have very shallow water and are either carpeted by exotic vegetation or have no vegetation at all. In comparison, peat lakes are typically stained brown, are deeper, more acidic, and have better water quality and more often contain native fish and vegetation.

below **Lake Rotomanuka North; a small, mostly mineralised lake in the Hamilton Basin. Lake Rotomanuka was once one lake, but drainage lowered the level and split it into two lakes, North and South; it is surrounded by a shallow layer of peat on top of which is mineralised soil. Note the surrounding raupo and kahikatea in the background; pasture and introduced crack willow are also present in this picture. In the summer of 1996–97 the oxygen weed *Egeria densa* which had filled it for many years suddenly died, darkening the lake with rotting vegetation and thereby killing other plants; it is now eutrophic. Its southern partner is in a worse state, being hyper-eutrophic, having served as the recipient of a major drain discharging effluent from dairy farms. Waipa District.**

DUNE LAKES AND WETLANDS

Sand is heaped by the action of wind and waves into ridges and depressions. Wetlands and lakes can accumulate in these depressions; such 'deflation' lakes accumulate water either because drainage of precipitation through the sand is impeded by varying degrees of subsoil impermeability in a hollow (e.g. the Kai Iwi lakes, from podzolisation of the soil) or because the depression dips below the groundwater level (e.g. Whatipu in west Auckland). Dune barrage lakes are formed by a sand dune blowing across a stream (e.g. Lake Ototoa in the South Kaipara Peninsula, where there is a block in a stream valley; the depression is also deep enough that it approaches groundwater level). Lakes such as the Kai Iwi lakes that are more reliant on rainfall for recharge are less fertile than those that receive nutrient inflows from streams and other run-off from surrounding land.

Dune lakes and wetlands are very common all the way up our very sandy western coast, particularly on the large sand barriers of the Awhitu Peninsula, the Kaipara peninsulas and the Aupouri Peninsula. There were also dune lakes on the east coast of Northland — one small one remains, behind Ruakaka beach south of Whangarei. Rare inhabitants of Northland's dune lakes include the dwarf inanga (*Galaxias gracilis*) and the small plant *Trithuria inconspicua*; some dune lakes contain no exotic species. However, if nutrient levels rise in these lakes, most commonly from agricultural run-off, the resultant algal blooms can destroy the native ecology; exotic plants such as the oxygen weed *Egeria densa* will also stifle native life if they manage to invade.

Most dune lakes are also very recent, less than 6.5 ka (after sea levels stabilised at their current levels), although Lake Taharoa — the largest of the Kai Iwi lakes — is more than 50 ka.

below **A dune lake and swamp, behind Te Werahi Beach, Far North District.**

RIVER ENVIRONMENTS

The rivers of the north are of many kinds — the slow, estuarine and brackish rivers of the North Auckland Peninsula; the mighty but tamed Waikato River, powering dams and draining dairy farms; the braided rivers which drain the axial Raukumara Range, such as the still-wild Motu; and the many smaller streams and rivers throughout the north.

Rivers represent a very diverse range of environments. Large, slow-flowing rivers such as the Wairoa in Northland or the Waikato may have very similar characteristics and biological communities to large lakes, although the erosive power of the water will tend to combat infilling by sediment and vegetative material; shallow, fast and stony streams are very different. In the uplands, where small rivers run quickly down steep valleys, there is excellent mixing of the waters which, as a result, are oxygen-rich. Rapids and waterfalls form when hard rock meets soft and the latter is eroded. The rivers pick up chemicals such as chlorides and sulfates from the surrounding rocks as well as solid particles such as silt and rocks ('the load'). As they head into their lower, flatter reaches, river velocity decreases, some sediment previously held in suspension sinks to the bottom and downwards erosion decreases. At the same time, sideways erosion increases at the outside edges of bends, causing the river to become increasingly winding and leading to the formation of features such as oxbow lakes when such bows are eventually cut off.

If the river slows down sufficiently that it cannot carry its sediment load all the way to the sea, it may end up depositing so much sediment in its bed that the bed starts to rise; a small flood then spills it over into a different course so that it starts to meander over its own alluvium. This gives rise to braided shingle rivers such as Canterbury is famous for but which are also found in the north, especially draining the axial ranges in the eastern Bay of Plenty and Gisborne District such as the Waiapu near Ruatoria; one can even observe this phenomenon on a miniature scale on streams running down a relatively flat, sandy beach. As mentioned, our mightiest river, the Waikato, once built up the floor of the Hamilton Basin (Hinuera Surface) as a braided river but eventually, as the amount of sediment it carried decreased, the Waikato started to cut down into its alluvium and became fixed in its course. Many of the rivers outside the axial ranges have stable banks and carry less sediment than braided rivers, allowing them to become fixed in position like the Waikato; many of our smaller rivers, among them the tributaries of the Waikato, have already dropped a lot of sediment into the lake from which the main river arises — in the Waikato's case, Lake Taupo.

opposite **The rocky Waioeka River, Opotiki District, which drains the greywacke axial rages. This is a turbulent and hence well-oxygenated river. The hardness of the rock stabilises the steep sides of the gorge, while the high rainfall nourishes both forest and river.**

top **The braided nature of the Waiapu River near Ruatoria, Gisborne District, is clearly visible in this aerial photograph.**

middle **A northern river; the Waipoua River runs through our largest remaining kauri forest. This photograph was taken in late January, at a time of relatively low flow. Far North District.**

bottom **A river in old age, the Waikato near Tuakau, Waikato District. Note the bends and small islands within the river.**

LIFE IN LAKES AND RIVERS

Given the diversity of lakes and rivers, it is obvious that different species will prefer some more than others and will even prefer to dwell in one part of a single water body as opposed to others. Thus, we should first review the different zones of each type of water body.

Lakes can be divided into a littoral zone, around the edge of the lake and where large, easily visible plants (macrophytes) grow; a benthic zone (the bottom of the lake), the substrate of which determines the community that lives there, usually feeding on detritus falling from above; and a limnetic zone, the open surface water well away from the littoral zone, which, being well lit, is where most of the phytoplankton lives and hence where the majority of photosynthesis takes place. In between the limnetic and benthic zones is the colder profundal zone, poorly lit and biologically quite distinct. The littoral fringe varies between lakes; for instance, around hydro lakes with their fluctuating water levels, this fringe is very much poorer in terms of inhabitants.

Rivers are distinguished from lakes by their flowing water, which makes for a constant resupply and drainage of nutrients, sediment and other material; this makes them more 'open' than the 'closed' systems of lakes. The velocity of the water also influences the biological community that lives both in the river (aquatic) and around it; a well-developed riparian (river bank) zone similar to the littoral zone of lakes also occurs on the shores of large, slow-flowing rivers with large floodplains, such as Northland's Wairoa River

left **A well-developed littoral fringe of erect, semi-emergent sedges around a dune lake, Lake Ngatu near Ahipara, Far North District. Note particularly the *Eleocharis sphacelata* (kutakuta) reedland which dominates the deeper water in the middle distance, an important ingredient in Maori weaving.**

or the Waikato River, between low- and high-water marks. Small, fast-running headwater streams typically have a smaller riparian zone, particularly since floods in such streams don't usually reach far up their steep sides. Conversely, they have well-mixed, oxygen-rich waters and, if they run through the bush, a plentiful supply of nutrients from overhead leaf fall. Hence they provide an excellent habitat for plants and animals that can tolerate the turbulent waters, typically quite a distinct community from that in slower waters.

In open water, there is generally more life near the surface where sunlight penetrates and oxygen levels are higher. However, many factors influence the amount of life present and this varies as the seasons change.

- The clearer the water, the more sunlight can penetrate to deeper levels and the greater the depth to which the littoral fringe descends and encroaches on the open water of the lake proper.

- Light is reduced in those waters shaded by native or exotic trees; before the coming of humans, many small lakes and rivers were much more shaded than today; land clearance has decreased the amount of shade and increased light levels. As a result, algal primary production has increased.

- Oxygen levels at depth can vary depending on the season; in summer, the surface water is warmer than that at depth, creating an invisible barrier (the thermocline) where the temperature suddenly becomes colder; since cold water is heavier than warm water it remains at the bottom, and, cut off from the atmosphere, over summer it slowly becomes hypoxic (low in oxygen). This deoxygenation can lead to the death of most life forms during summer in some lakes and is particularly true of lakes not exposed to much wind, which is otherwise a potent mixer of water; flowing water, of course, does not have this problem. In winter, the surface water cools and sinks, leading to greater oxygenation at depth; mixing is also assisted by the tendency of storms to occur in winter. For instance, Kaipara District's Lake Kai Iwi usually stratifies in spring and/or summer at 9–13 m deep while the adjacent, larger Lake Taharoa stratifies at between 23 and 34 m. There is a concern that if significant global warming occurs, Lake Taupo could cease to completely mix in winter.

- Since summer is the most light-intense time, there tends to be increased biomass by late summer (although less so than in some other parts of the world) and, particularly at that time of year, the supply of nutrients becomes the main limiting factor on growth. Interestingly, however, the peak of phytoplankton production in Lake Taupo occurs when the water temperature is near its minimum, 10–11°C, unlike another deep New Zealand lake with similar winter-time surface temperatures, Lake Brunner on the South Island's West Coast or the cooler and deeper Lake Waikaremoana, the north's second largest lake. This may be driven by deep mixing and overturn of the water column at this time of year, due to loss of thermal stratification, which returns nutrients to the surface layer. Nutrient and other inflows to this lake, surrounded as it is by pasture, two small towns (as well as native vegetation) and volcanic rock, is unlike the other two examples, which are almost completely surrounded by native vegetation and are far from volcanic influences; this could explain the difference. Phosphorus is known to be a major limiting factor in phytoplankton growth in many North American and European lakes and no doubt is an important limiting nutrient in New Zealand lakes and rivers, although we often use more phosphorus in our fertilisers and areas of recent volcanic activity also tend

to be high in phosphorus; further, we tend to plant nitrogen-fixing clover rather than using more-soluble inorganic nitrogen fertilisers, resulting in relatively less nitrogen run-off, and there are fewer atmospheric nitrogen oxides in our atmosphere than in the more polluted Northern Hemisphere. Therefore, nitrogen may often be a more important limiting factor in many of our lakes. Other limiting nutrients may include silicon (for diatoms) and various micronutrients, such as iron, molybdenum and cobalt. Relatively clear waters with only small amounts of nutrients (phosphorus and nitrogen) and a low level of chlorophyll (algae) are termed microtrophic; we call lakes with increasing levels of nutrient enrichment oligotrophic and mesotrophic and those with even more nutrient-laden waters eutrophic.

- Different animals also prefer different habitats; even within the same small, upland river, browsers may prefer to nibble the stable biofilm in ponds whereas filter-feeders find it easier to catch floating plankton in the turbulent riffles (short stretches of shallow stream with a coarse bed); crustaceans are also much more numerous in the stiller ponds than in the rapid riffles.

- Grazing pressure from animal herbivores limits the growth of plankton (e.g. zooplankton) and the macroscopic flora. For instance, *Egeria densa* has been targeted by introduced species such as Chinese grass carp (*Ctenopharyngodon idella*), which was introduced to Lake Omapere to eat all the *Egeria* in the lake.

Introduced macrophytes, especially submerged weeds and willows, have had enormous success in their spread, even though most have to be spread by humans as they do not produce seeds in New Zealand. The result is that finding a completely native littoral fringe anywhere is now rare.

SMALL ORGANISMS: PLANKTON AND PERIPHYTON

Just like the sea, freshwater lakes and rivers contain a plankton of suspended organisms that are incapable of swimming against a current. This consists of the bacterioplankton (decomposers); the producers, algal phytoplankton (such as the predominantly unicellular diatoms) and blue-green algae (not actually a plant at all but closer to bacteria and more properly termed cyanobacteria); and zooplankton, tiny animals (mainly small crustaceans and insect larvae, covered later in this chapter) which feed on the phytoplankton and are in turn fed upon by fish and larger invertebrates. Desmids, a type of green alga particularly common in New Zealand freshwater, can impart a green sheen to our waters. Some of these microscopic organisms also form a biofilm coating the sediment on the bottom, on which browsers graze. In particular, green algae (as opposed to red or brown) tend to inhabit freshwater rather than seawater and can form a large zone 30 cm thick around the edges of lakes and reaching to a depth of more than 30 m.

below **Green algae, Webb Creek, Thames-Coromandel District.**

left **The green sheen lining the rocks is periphyton, in a late-summer waterhole in the Kauaeranga River — perfectly healthy water. Watch out for those slippery stones! Thames-Coromandel District.**

If conditions are right, for instance in a pond in summertime experiencing a high nutrient run-off and with no shade around the edges, algal blooms may form, caused by organisms such as the blue-green alga (cyanobacteria) *Nodularia spumigena*. Such conditions are much more likely to occur in today's more-eutrophic, modified lowland lakes than once they were, as described below.

Periphyton is the name given to the green or brown 'slime' (biofilm) found on rocks and wood within our streams and freshwater (and wetlands of all types). The most prominent members of periphyton in New Zealand are diatoms, followed by other algae (particularly green algae), cyanobacteria and other bacteria and fungi. Periphyton tends to grow best in slow-flowing waters or lakes with minimal bed disturbance, but can be stripped away by floods. Some particular species of interest in the north include the 'blanket weeds' *Cladophora glomerata* and *Rhizoclonium* species around the Central Volcanic Plateau, which enjoy the mineral-rich papa–mudstone, agricultural run-off and high summertime temperatures; the algae *Ulothrix zonata* and *Stigeoclonium* species of the cooler, less-enriched axial ranges; and *Campsopogon caeruleus*, the ropy strands of the filamentous red alga of the north found in nutrient-enriched streams. However, some agricultural lowland streams are so choked by macrophytes that periphyton is excluded. Grazing by invertebrates is probably important in the control of periphyton, especially in stable environments.

LARGER PLANTS

Larger plants, such as angiosperms, that are easily visible to the naked eye are termed macrophytes. Also commonly visible are coatings of bryophytes (mosses and liverworts) on the bottoms of lakes and attached to stream boulders; ferns, common in fast-flowing streams; and charophytes, macroscopic algae that resemble submerged vascular plants and tend to live in slow-flowing rivers and lakes, attaching to other plants or sediment like their seaweed cousins.

Our freshwater flora is relatively species-poor, predominantly non-endemic (only 29% of aquatic plants are endemic; most non-endemic natives are also found in Australia), and is generally perennial, unlike in North America and Europe where there is often a dramatic decline at the end of summer.

In many waterways, native macrophytes have been pushed out by more-vigorous introduced species, which sometimes grow too vigorously, exhaust the available nutrients and then die, eventually stabilising at a lower biomass.

Many higher plants, mostly angiosperms, live on the littoral fringes of freshwater bodies. Most have their roots in the soil below and emerge above the surface, including raupo (*Typha orientalis*), erect reeds and many native sedges such as the rushes; they can grow in water up to 2 m deep. An important consideration is that where there is water instead of air between the soil particles, microbes and animals deplete the oxygen faster than it can be replaced, since gases diffuse more slowly in water than in air; wet soil contains less oxygen, favouring anaerobic bacteria — at the extreme, the methane-producing and odiferous (the latter mainly from sulfurous compounds) Archaea.

To cope with such conditions, plants growing in wet environments (less than 5% of vascular plants can cope with being waterlogged) may have some of the following adaptations:

- seeds generally germinate in shallow areas that can dry out in summer; as the plant grows, it spreads into deeper areas
- vegetative growth (rather than from seeds)

allows plants to bypass the hazardous seedling stage; this includes many introduced species, such as crack willow

- flexible morphology — plants can do different things under different conditions; in deep water, leaves and shoots elongate very rapidly to get above the water (depth accommodation response), and leaves above the water may be different from those below (heterophylly), to take advantage of the different conditions

- roots are adapted, e.g. containing air spaces, to allow oxygen to diffuse down to them.

Perhaps the most prominent littoral plant is raupo, a tall emergent brown (or, in summer, green) and thick stick-like plant, which grows in the still, shallow fringes of many of the lakes and ponds of northern New Zealand as well as along slower watercourses, in swamps and in seepages up to lower montane altitudes. It attains a height of up to 1.5 m; fertile waters and areas of high nutrient run-off from surrounding

opposite **The Arohaki Lagoon, in the Whirinaki Forest Park (Whakatane District), surrounded by wetland vegetation and, in yet shallower water, kahikatea swamp forest. Raupo, common in many lakes, is not visible in this image; the foreground is dominated by reeds while manuka is visible on the far shore of the lake, just in front of and below the tall kahikatea.**

above **The edge of the northern Wairoa River, near Dargaville (the Tangihua Range is in the background): almost lake-like riverine margin with marginal sedges and, in shallower water, raupo. In the left middle distance is some remnant kahikatea forest; note also the invasive willows in the right middle distance. Kaipara District.**

land increase its abundance, to the detriment of other species; however, its rapid growth absorbs not only nutrients but also pollutants such as effluent from farm animals, sewerage and other such sources. It also decomposes rapidly, meaning that little ends up as peat, and provides a habitat for eels, waterfowl (e.g. fernbirds, crakes and bitterns), spawning whitebait (inanga) and other native fish; hence, it is an extremely important component of our flora. It is not endemic to New Zealand as it can also be found throughout eastern Asia and Australia.

As well as raupo, other tall emergent littoral plants may be found in our lakes, predominantly the tall green native reeds of the family Cyperaceae, the sedges, such as *Machaerina* species (*Machaerina* now being the accepted term for the genus that includes those species formerly placed in *Baumea*), *Eliocharis sphacelata* and *E. acuta*, usually growing on the lacustrine or riverine margin of raupo. Introduced species in this habitat include gypsywort (*Lycopus europaeus*), Manchurian wild rice (*Zizania latifolia)*, a type of grass (and also a reed), and many others. We have no native water lilies; in this niche, exotic water lilies (*Nymphaea* species) have flourished, to the detriment of native pondweeds (*Potamogeton* species), milfoils (*Myriophyllum*) and charophytes.

When plants become established in lakes, they begin to change the environment as they trap sediment around their roots; as the sediment builds up (aggradation), the lake becomes increasingly shallower, gradually becoming dry land. The sequence of colonisation echoes the order in which different plants are found, going from open water to dry land. Hence, species such as *Eleocharis* sedges act as first colonisers in deeper water, eventually gathering enough silt to allow other sedges (*Machaerina* species) and raupo to become established.

Raupo in particular raises the bed of a lake to approximately the water level, and, when it does so, gives way to New Zealand flax (*Phormium tenax*), toetoe (*Cortaderia toetoe*) and *Carex secta*. Further away from the lake one will often then find manuka (*Leptospermum scoparium*), tolerant as it is of poorly drained soils, together with koromiko (*Hebe stricta*), karamu (*Coprosma robusta*) and several other *Coprosma* species. Cabbage trees (*Cordyline australis*) are often the first trees, followed by closed swamp forest typically featuring kahikatea (*Dacrycarpus dacrydioides*) as the most prominent species but also such wetland trees as pukatea (*Laurelia novae-zelandiae*) and the smaller swamp maire (*Syzgium maire*). Many plants from previous stages may still be found in this forest, along with epiphytes such as kiekie (*Freycinetia baueriana* subsp. *banksii*). Eventually, swamp forest itself gives way to more-standard conifer–hardwood forest. Cabbage trees underwent a serious decline in the 1980s and 1990s, starting in Northland, caused by a bacterium probably transmitted by a sap-sucking insect such as the Australian passionvine hopper (*Scolypopa australis*). Fortunately, this epidemic would now appear to be lessening.

As one goes deeper into a lake, from the littoral fringe into the shallows and mid-depths, one finds bottom-anchored submerged and semi-floating plants. These plants also trap sediment and build up mounds of debris, again gradually filling in the edges of the lake. Floating plants are rare among our natives, but we do have the free-floating, nitrogen-fixing fern *Azolla rubra* (being replaced by the introduced *A. pinnata)* and native duckweed (Lemnoideae); floating plants may entirely fill a still, undisturbed pond. They thrive in eutrophic waters. There are, of course, also exotic floating species which threaten our lakes, such as the water hyacinth (*Eichhornia*

crassipes), the fern *Salvinia molesta* and the hornwort *Ceratophyllum demersum*. This last can also grow at significant depths, down to 14.5 m to even displace charophytes, and it can be up to 7 m tall; it also secretes chemicals that inhibit the growth of phytoplankton and cyanobacteria. Given these characteristics and its vigorous growth, it will little surprise the reader to know that it is a serious weed, spread by its use in aquaria. Introduced floating-leaved but bottom-rooted plants include, amongst others, water lilies and water poppy (*Hydrocleys nymphoides*), while natives include representatives of the aforementioned pondweeds and milfoils.

The most common submerged plants today are the introduced tall-growing oxygen weeds (Hydrocharitaceae) such as *Elodea canadensis* and *Egeria densa*; more recently, the mid-depth *Lagarosiphon major* has made an appearance, although it loses out to *Elodea* under eutrophic conditions. In very clear water, *Elodea* can grow up to 10 m deep. These plants seem to be more prolific in New Zealand than in their native lands — perhaps due to a relative paucity of herbivores, or perhaps due to the fact that our lakes don't get as cold in winter as they do in the northern continental landmasses, meaning that they can become more perennial. They can also grow taller and faster than the equivalent mid-depth native plants and, by growing further out in deeper water, can block the edges of lakes for much greater distances from the shore, not only stifling the indigenous species but also reducing wave action as well as obstructing hydroelectric power generation, a very important function of the Waikato River. Their dominating presence can also prevent light from penetrating through the water column, leading to anoxia in the bottom sediments and release of phosphorus, thus changing the whole ecosystem of the lake to the point of causing the death of all submerged vegetation; this has happened in Lake Omapere and various Waikato lakes and is described later.

above **Oxygen weed, Arohaki Lagoon, Whirinaki Forest Park, Whatakane District.**

The native submerged vegetation of our lakes once consisted of a 'low mixed community' close to shore and a taller 'mid-depth' community in deeper water; even further out remains the domain of characean algae. For instance, on the gently sloping sheltered shores of Lake Rotoiti, in water of about 0.1 to 1.8 m deep one can find very small plants such as *Glossostigma elatonoides* and waterworts (*Elatine* species). Over time, this low mixed community gradually accumulates sediment to grow gradually expanding mounds. Further out are the mid-depth, taller natives such as the pondweeds and milfoils; this community in particular has been displaced to greater or lesser degrees on the Rotorua lakes by *Elodea* and *Lagarosiphon*.

Other submerged native aquatic plants include various mosses (e.g. *Warnstorfia fluitans*, which can grow down to 3 m in still, clear water) and liverworts, the fern *Pilularia*

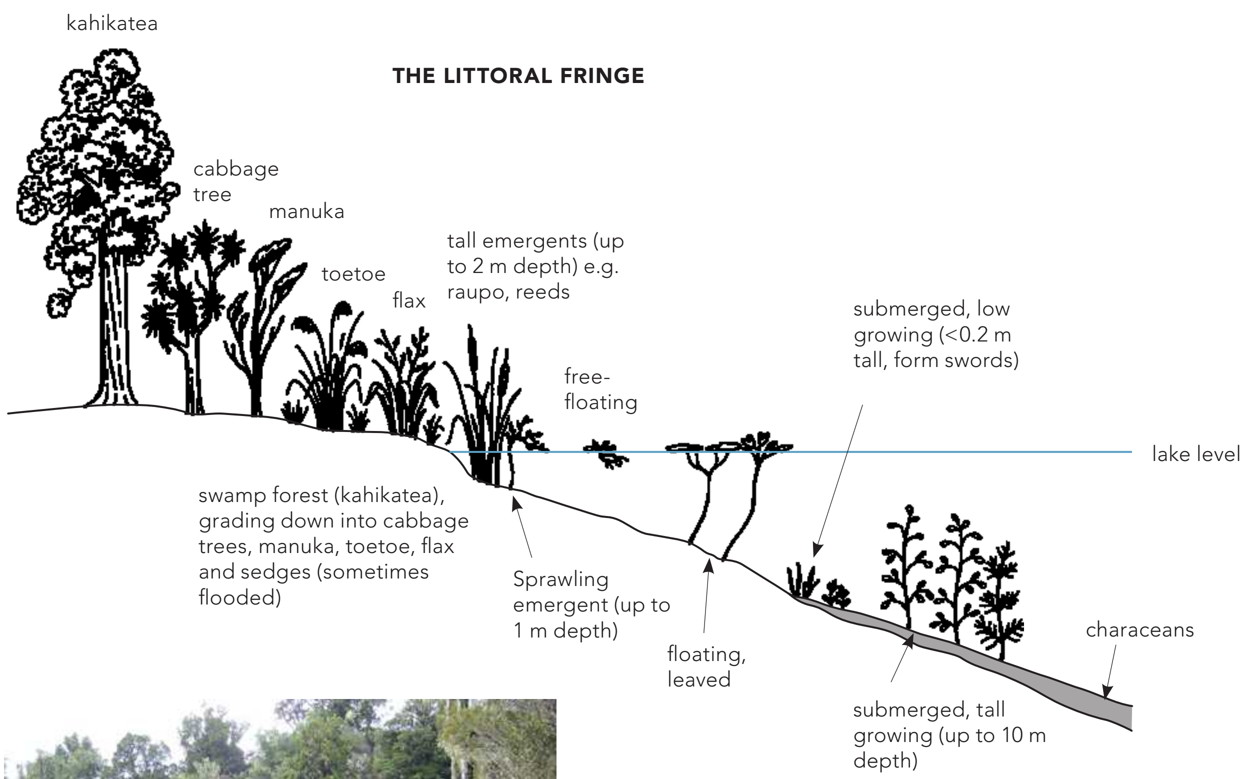


Figure 2 **A littoral fringe. The littoral zone may be divided into subzones: the eulittoral, between the high-water mark and the shore (but subject to waves); the upper littoral, permanently wet down to 2 m deep and containing emergent plants, free-floating or attached floating-leaved plants and low mixed plants; the middle littoral, where wave exposure is less and tall rooted plants dominate (e.g. oxygen weed, milfoils and pondweeds), extending down to 7 m in clear lakes; and the lower littoral zone, dominated by the macroalgal charophytes. Bryophytes and cyanobacteria, adapted to extremely low light, may also fill the transition from the littoral zone into the soft sediments of the bottom, the profundal zone.**

above **The littoral fringe, Arohaki Lagoon, Whirinaki Forest Park, Whakatane District. Note the tall emergent reeds in the left foreground, which grade into manuka and kahikatea in the right foreground. In the middle centre is a cabbage tree. Further back, on higher ground, rimu and tawa are visible.**

novae-hollandiae, the 'fern-ally' quillwort (*Isoetes kirkii*) and angiosperms such as the relatively tall (up to 3 m) *Ruppia polycarpa*, the horse's mane weed. Some *Ranunculus* (buttercups and related) species also thrive in aquatic environments and the bottoms of Northland's dune lakes may be graced by the very small *Trithuria inconspicua*, which also lives in western Southland and Fiordland in the southern South Island (a disjunct distribution). Plants adapted to life underwater enjoy a more uniform habitat than terrestrial plants, but since the amount of oxygen dissolved in water is less than that in air present in air, volume for volume, they must adapt to decreased oxygenation.

In still-deeper water, below the depth angiosperms can grow at (around 10 m), one may find large expanses of characean algae (mainly *Nitella* and *Chara*), a family of submerged green algae that occur widely in water containing less than 1% salt, covering soft substrates, with other seasonal

filamentous algae coating shingle and rocks. Charophytes dominate these depths, but they can also be found, sometimes forming meadows, at shallower depths also. Charophytes are interesting in that they are the closest living relatives of the ancestors of land plants. Deep-water bryophytes can also grow at such depths.

Some algae form large unattached mats (metaphyton) that float near the water surface.

Some aquatic plants, including some *Ranunculus* species, can grow both submerged, in a more etiolated form (i.e. paler, due to less chlorophyll, but with longer and weaker stems so that their growing tips can reach some sunlight), and more compactly on damp ground. Also, some terrestrial plants, such as *Sphagnum* mosses and *Carex* tussocks, may invade waterways, as does the introduced crack willow, a particular pest which tolerates both deep immersion and aggradation and suppresses adjacent native plants on both the aquatic and landward sides of the margin with its summer shade (being deciduous), mats of roots and heavy leaf litter.

REEDS, RUSHES AND SEDGES: A DEFINITION

The term 'reed' encompasses those tall, grass-like, non-branched wetland herbs that grow from the ground, up through water, to emerge on the surface. They are all members of the order Poales (although the reverse is not true), and include members of the families Poaceae (grasses), Cyperaceae (sedges), Typhaceae (particularly raupo), Sparganiaceae and Restionaceae (restiads; primarily found in Africa and Australia but also in New Zealand).

Sedges are monocotyledonous plants of the family Cyperaceae. They appear very similar to grasses or rushes, but their stems are usually triangular and their leaves are arranged spirally in three ranks (as opposed to the two of grasses); many are associated with wetlands or poor soils. Sedgelands are those ecological communities dominated by this family. Examples include the tussocky *Carex* and the rush-like *Machaerina*.

Rushes are members of the monocotyledonous Juncaceae family and also resemble grasses. Most are wetland perennials and the largest genus is *Juncus*. They are evergreen, with alternate and tristichous leaves (i.e. three rows of leaves up the stem, each row of leaves arising one-third of the way around the stem from the previous leaf).

A rhyme to help differentiate between grasses, rushes and sedges (although not always completely reliable) is: 'Sedges have edges, rushes are round; grasses have nodes from their tips to the ground.'

PLANTS OF RIVERS AND STREAMS

The plant communities of streams and rivers are influenced by the velocity of the water flow. Rivers have an erosive power that acts to inhibit the infilling of lakes; there is a constant battle between erosion by water and sedimentation, assisted by vegetation, as it reduces the velocity of flow and stabilises the river bank. Slower-moving large rivers typically have a more well-developed riparian zone and aquatic plants are generally not found where the velocity of the water exceeds 1 m/s. Plants that tolerate relatively swifter waters, such as water brome (*Amphibromus fluitans*) and the naturalised water buttercup *Ranunculus trichophyllus*, have streamlined forms to reduce drag along with well-anchored roots. Rooted vascular plants are also generally absent from streams whose bottom is unstable (e.g. gravel-bed rivers) and the large algae are similarly mainly confined to slow-flowing rivers. On the other hand, bryophytes (liverworts and mosses) may be common on the boulders of faster-flowing streams and may provide more stable microhabitats for other organisms.

above **A stream in the bush with little specifically riparian vegetation, but an abundance of moisture-loving plants. Morere Springs, Wairoa District.**

Nevertheless, forested streams provide a habitat for many plants that depend on consistently moist, humid and shaded conditions, such as mosses and ferns. Other small native plants that may be encountered include native buttercups (all buttercups are members of the genus *Ranunculus*), the New Zealand iris (*Libertia ixioides*) and the New Zealand calceolaria (*Jovellana sinclairii*). *Coprosma rotundifolia* favours the bank and from Waihi south one may encounter the tree daisy *Olearia cheesemanii*. Native brooms (*Carmichaelia* species), the kowhais *Sophora tetraptera* and *S. microphylla* and some lacebarks (*Hoheria* species, a native genus) also enjoy living 'streamside'.

BRACKISH WATERS

As rivers approach the sea and become estuarine, the communities living there must become increasingly salt-tolerant. The number of plants that can grow in and around freshwater far exceeds that of those which can grow with their feet in the briny, but many plants are tolerant of some salt; with increasing salinity, the number that can tolerate such conditions gradually drops such that, in northern New Zealand, only *Zostera* species (seagrass) can survive complete immersion in sea water.

FRESHWATER FAUNA

Distribution

The animals that inhabit our freshwater can be divided into those that are primarily

aquatic, such as molluscs, and those that live most of their life on land but have an aquatic stage. Lakes and rivers have a much more diverse fauna than swamps and bogs (discussed in detail in a later section), as the latter are often more acidic and anaerobic (due to stagnation and bacterial decomposition of vegetative material using up the available oxygenation) and the water may be obscured by the vegetation above, preventing sunlight from penetrating and inhibiting photosynthesis.

The invertebrates of New Zealand's rivers and streams tend to be highly endemic at the species and genus levels and there are few introduced species. Many species, such as the freshwater snail *Potamopyrgus antipodarum*, are represented by one widespread species with few or no near relations and many Northern Hemisphere families are entirely missing. Dominant invertebrate groups tend to be the insects (particularly mayflies, stoneflies, caddisflies and true flies), crustaceans, molluscs and annelids (oligochaete worms and leeches). In fast-flowing headwater streams, the fauna is limited to those that can tolerate the conditions, such as mayflies, caddisflies, chironomids (midges), the snail *P. antipodarum*, banded kokupu, red-finned bully, dwarf galaxiids and torrentfish; crustaceans are much less tolerant of such waters. Birds, such as blue duck (whio), may also be found dining on stream invertebrates. The more disturbance-prone the stream (e.g. floods and drying), the less diverse the fauna; it becomes dominated by mayflies and chironomids with less detritus and algae growing on the boulders also.

A similar invertebrate fauna may be found in the littoral zone of lakes. Insect larvae, of caddisflies and mayflies, often dominate the rocky shores (upper littoral), but the macrophyte beds tend to contain the most diverse lake fauna, the main grazer usually being *P. antipodarum*, along with caddisflies and chironomids, the latter also being, with oligochaete worms, important detritivores in the soft sediments of the lower littoral. Crayfish and phytoplankton-filtering freshwater mussels (*Echyridella* species) may also be common, both in the littoral and below.

Most herbivores feed on periphyton, detritus and bacteria growing on macrophytes rather than the plants themselves, with the exception of crayfish and larvae of the aquatic moth *Nymphula nitens* (which feeds on *Elodea canadensis*). No extant native fish feed on algae or detritus. They are in turn consumed by predatory invertebrates (e.g. dragonfly and damselfly larvae), small fish (mainly common bullies *Gobiomorphus cotidianus*) and birds. Predators of common bullies in both the littoral and benthic zones are predominantly native fish such as eels (*Anguilla* species) and koaro (*Galaxias brevipinnis*), with eels being the predominant benthivore in shallower lakes. Common bullies are the main primary consumers below the littoral, consuming mainly snails and chironomid larvae, but in Lake Rotoma they were found to feed mainly on small crustacea down to 70 m, and these may therefore be the main secondary producers in deep, oligotrophic lakes.

On the surface of our lakes common invertebrates include bugs (order Hemiptera) adapted to living supported by water surface tension, including water skaters (*Microvelia*) and water measurers (*Hydrometra*) and, just under the surface, waterboatmen and backswimmers.

Unlike adults, the larvae of most native fish tend to feed in the open-water (limnetic) zone, where a diatom-based phytoplankton is predated by a crustacean zooplankton.

Koaro were probably the dominant limnetic fish in most New Zealand lakes

before the introduction of trout, acting as both primary and secondary consumers, but in most large North Island lakes now their place as a primary consumer in the limnetic zone has been taken by the more abundant common smelt (*Retropinna retropinna*), while the introduced rainbow trout (*Oncorhynchus mykiss*) is the predominant limnetic piscavore (eater of the other fish, i.e. a secondary consumer). However, trout are quite capable of feeding directly on snails, chironomids and other invertebrates, which they do in Lake Otamangakau where smelt and common bullies have not been introduced. Eels are the predominant piscivores in our smaller, shallower coastal lakes that are not suitable for trout because they warm up too much in summer and generally do not have spawning streams, although introduced species may be found in some. The predominant limnetic planktivorous fish in these lakes are the larvae of common bullies as well as young galaxiids and smelt.

Compared with Europe or North America the variety of larger animals, such as non-planktonic crustaceans, molluscs and fish, is not great; we have very few secondary consumers in comparison with the Northern Hemisphere and relatively simple food webs. Perhaps this is because of our colder conditions, especially compared with the more southern parts of the northern continents in which animals could find refuge during the Pleistocene glaciations (the periodic changes in sea level with intermittent glaciations which changed our small islands much more than the large continents), and our geological instability. For instance, the food chain in Lake Taupo (which has, of course, exploded several times in the not-so-recent past) has, as its top predator, the introduced rainbow trout, feeding on smelt which in turn eat the zooplankton such as *Bosmina meridionali* (water flea, a type of crustacean). That animal in turn grazes on phytoplanktonic diatoms, green algae and possibly bacteria.

CRUSTACEANS

Crustaceans, a type of arthropod, as are insects — and equally numerous but more common in aquatic rather than terrestrial environments — are generally small and unable to hold their own in turbulent water; they live mostly as zooplankton or in the substrate at the bottom of the water. Such crustaceans include waterfleas (order Cladocera), ostracods and copepods (the 'oar-footed').

Copepods, the 'insects' of the sea, may be the most numerous animals on Earth and, as such, form a vital link in our freshwater food web, consuming algae, phytoplankton and protozoans while being predated upon by larval fish and large crustaceans. In the marine environment, they are the main food of hoki larvae, giving rise to our most important commercial fishery. Some copepods have very restricted ranges — *Paracyclops waiariki* inhabits only the thermal waters of Lake Rotowhero, which range in temperature from 29.5°C to 37.5°C. Ostracods, tiny bivalved crustaceans enclosed in a carapace for protection, may inhabit both the banks and the bottom.

Other, larger crustaceans include isopods and amphipods. The largest crustacean is the freshwater koura or crayfish, one of the order Decapoda ('ten-footed' or 'ten-legged'), represented in the north by *Paranephrops planifrons*. It is essentially a bottom-dweller, but may come closer to the surface when the waters become stratified in summer and during the night to feed, in turn providing food for trout and shags. The larvae of most decapods include a free-swimming planktonic form.

New Zealand's tadpole shrimp, *Lepidurus apus viridis*, outsmarts its predators by

top ***Austridotea annectens*, the endangered New Zealand freshwater isopod, Taumutu Lake Ellesmere, Selwyn District (Canterbury). These creatures have changed very little from their Gondwanan ancestors which evolved at least 325 million years ago and are hence more ancient than both tuatara and weta. Photograph: Paddy Ryan.**

bottom **Freshwater crayfish at the Hydrocamp, Kauaeranga Valley, Thames-Coromandel District.**

living in temporary ponds which dry out periodically; the shrimps survive such desiccation but the predators do not. We also have tiny members of the superorder Syncarida, little changed since the Carboniferous and which are true living fossils. They usually live underground — in groundwater (revealed in springs) or caves with streams and sand banks. We have but one freshwater 'true' shrimp (i.e. a decapod crustacean), *Paratya curvirstris*, and the mysid shrimp *Tenagomysis chiltoni* is abundant in some turbid lower Waikato lakes such as Lake Waikare (*T. novaezealandiae* has also been found in New Zealand freshwater); both are also present in brackish water along with other mysid shrimps. There is also a native freshwater crab, *Amarinus lacustris*, which may have hitched a ride here from Australia on a bird which was blown off course; many juvenile crustaceans are spread from one water body to another in the feathers of birds.

INSECTS

Many insects also call the freshwater home, often for their larval stage and particularly those that do not undergo a complete metamorphosis (i.e. the more primitive ones), such as mayflies (order Ephemeroptera). Further details on insects can also be found in Chapter 7.

Mayflies eat organic debris and in turn are consumed by other insects such as the bottom-dwelling larvae of the dobsonfly (*Archichauliodes diversus*), as well as by trout and crustaceans. Mayflies are much more common on the mainland than on our smaller islands and are also an excellent indicator of the health of streams, being more common in undisturbed forest than elsewhere; their larvae survive underwater by means of gills attached to their trachea. Different freshwater habitats provide homes for different species — for instance, the larva of the mayfly *Coloburiscus humeralis*, prefers stony streams but *Ichthybotus hudsoni* burrows into soft sediments. Some mayfly nymphs, e.g. those of *Nesameletus* species, live in swift waters, trapping food that floats past, their torpedo-shaped bodies lacking moving gills making such environments a necessity.

Caddisfly (order Trichoptera) larvae are almost all aquatic, mainly living in streams and rivers but also still waters. Some enclose

themselves within a case made of small particles such as sand, while others attach themselves to a hard surface with silk to avoid being dislodged by swift waters. Caddisfly adults are often substantially represented among the myriad tiny insects that one can gather on a lit surface near a stream at night.

Stonefly nymphs (order Plecoptera) are also aquatic and like to live under stones, away from direct light — hence the name. They also need relatively cool streams (≤13°C), which in the northern lowlands restricts them to shaded streams.

Many flies (order Diptera) also live in and around rivers and lakes, with their larvae having an aquatic stage. One of the most abundant are the chironomids, Chironomidae being a family of non-biting midges. Some species are adapted to low-oxygen environments (e.g. the benthic zone of lakes), such as the bloodworms, the bright-red larvae of many midge species which contain the oxygen-absorbing haemoglobin, and can be common in polluted waters, such as were common in Auckland's former sewage ponds in Mangere.

Biting flies includes mosquitoes (both natives, such as the whining nocturnal biter *Culex pervigilans*, and introduced, such as the non-whining *Aedes notoscriptus*) and sandflies (in the North Island, the biting sandfly (which elsewhere in the world would be called a blackfly) is the female *Austrosimulium australense*); sandfly larvae cluster on the upper surfaces of stones and driftwood in fast-flowing streams and rivers while mosquito larvae develop in still water.

Other flies include the craneflies (daddy long-legs, family Tipulidae) and lacewings (order Neuroptera); and, in damp places beside streams and in underground caves lives perhaps our most famous peri-aquatic invertebrate, the glow-worm (*Arachnocampa luminosa*) — actually a larval form (i.e. maggot) of a fly.

Glow-worms depend on those insects whose lifecycle includes a larval stage in freshwater, such as mosquitoes, caddisflies, mayflies and others; the streams that run beside their habitats — either above ground in moist, dark areas or, more famously, underground (especially at the Waitomo

left **The lacy 'fishing lines' of glow-worm larvae. Waitomo Caves (Ruakuri Cave), Waitomo District.**

Caves, one of New Zealand's biggest tourist attractions; see below) — carry these insects and other organic material into the caves or other hollows. When the adults emerge, they see what they think is the starry night sky above them and head for it, only to be trapped in the sticky threads that the glow-worm larvae hang down like fishing lines, to become food. The larvae only need about three such meals in their lifetime.

When glow-worms reach about 40 mm in length (at about 9 months of age), they turn into a pupa for 12 days before emerging as a fly with no mouthparts. The adult only survives for 1–2 days, its sole purpose being to reproduce and lay eggs.

Other insect groups represented in our freshwater include damselflies and dragonflies (order Odonata), bugs (order Hemiptera) and beetles (order Coleoptera). The Hydraenidae, Scirtidae and Hydrophilidae beetles are more common in forested streams, while Elmidae are often abundant in more-open streams, particularly those containing some sediment. As mentioned, we also have one dobsonfly, the toebiter, the larvae of which predate smaller invertebrates.

MOLLUSCS

The most common freshwater mollusc is the snail *P. antipodarum*, the main grazer of periphyton, although there are other snails both native and introduced. This little snail has become an invasive pest in many other parts of the world, including Europe, North America and Australia. Another mollusc, *Latia neritoides*, is a limpet-like creature of stony rivers and streams; freshwater mussels and clams, including New Zealand freshwater mussels and the clam *Sphaerium novaezelandiae*, complete our surface freshwater representatives of the phylum. In general, gastropod molluscs (i.e. snails) graze fine detritus and microbes whereas bivalves are primarily filter-feeders, eating small organic particles in the water column such as bacteria. We have but a relatively small freshwater mollusc fauna in terms of species diversity, but conversely have more filter-feeding molluscs in the shallow parts of our lakes than in many other places.

ANNELIDS

In sediments at the bottom live aquatic earthworms and other oligochaetes, often smaller than their terrestrial relatives. Leeches (Hirudinidae) are present, but there are no polychaete worms in this part of the country. Oligochaete worms are particularly common in organically polluted rivers.

OTHER INVERTEBRATE PHYLA

Representatives of the phylum Coelenterata in our freshwater environment include several *Hydra* species and the freshwater jellyfish *Craspedacusta sowerbyi*, found in several of our lakes as well as throughout most of the world.

Waterbears (phylum Tardigrada) are found almost anywhere there is water — even a drop — but are at most only 1.2 mm long and hardly ever observed by most people. Several are endemic to New Zealand.

Flatworms, tapeworms and flukes, members of phylum Platyhelminthes, are mostly parasitic although some can be found in our streams, usually hiding under rocks and weeds and staying away from bright light.

Nematodes, an extremely diverse phylum of slender, worm-like animals mostly less than 2.5 mm long, also dwell in the same environment and include both free-living and parasitic species, the latter awaiting the arrival of a host. One such is the shagworm (*Eustrongylides ignotus*), which parasitises in turn a copepod, a fish and then a shag as each host is, in turn, eaten by a larger animal.

FRESHWATER FISH

Although not as diverse as in many places overseas, for the reasons given above, New Zealand has almost 40 species of native freshwater fish, occupying several different niches. Most of our juvenile fish are planktivores (i.e. they eat plankton suspended in the water column, such as crustaceans), the most important being juvenile galaxiids (particularly koaro) and common bullies, as well as common smelts of all ages. Apart from the common smelt, most fish move on to feeding on insects and molluscs around the lake edge as adults. Adult eels are the predominant native piscivores and we have no herbivorous native fish. The only consumer of detritus is the grey mullet (*Mugil cephalus*), which is generally limited to shallow coastal lakes with sea access — with the particular exception of the Waikato River system where it penetrates up to Lake Karapiro and Te Kuiti. Interestingly, most of our freshwater fish are found either solely or largely in rivers; only three native species are primarily lake-dwellers.

Most native fish are quite secretive and hide from casual sight under boulders and other objects. Rather than in large rivers, their diversity is highest in small streams, perhaps due to competition and predation by trout and other introduced species in other waterways although other factors are probably also responsible for this distribution. Often they are much more nocturnal in habit than fish of other lands; whether this is because in pre-human times avian predators were the main enemy, or because we tend to have a relatively nocturnal invertebrate fauna — or some other reason — is not clear. Hence, the best way to spot native fish is by bringing a torch to a small forested stream.

GALAXIIDS

The most numerous of the native fish are the galaxiids, of which we have 25 species, representatives of two genera (out of seven worldwide). They are characterised by a lack of scales and a dorsal fin which arises quite far back; in the inanga (*Galaxias maculatus*), for instance, it arises as far back as the anal fin. What we term whitebait are in fact the juveniles of five different *Galaxias* species (inanga, koaro and the three kokopu), which hatch in autumn from eggs upriver left on grass that get submerged at the very highest tides; the hatchlings then migrate downstream to spend winter at sea, returning in spring/summer as whitebait and eventually laying eggs again as adults in autumn, after which they usually die.

Of all galaxiids, the inanga is the most

left **Giant kokopu, *Galaxias argenteus*, our largest galaxiids. Photograph: Paddy Ryan.**

right **Whitebait (*Galaxias* species). Photograph: Paddy Ryan.**

common whitebait fish and hence surely the most well known. Growing up to about 10 cm long (the longest on record was 19 cm), they are the only galaxiid to live in open water such as lowland rivers and pools as well as wetlands; they also live in South America and Australia.

A very similar galaxiid is the non-migratory dwarf galaxiid (*G. divergens*), which in the north is now only found in the headwaters of the Waihou River and in scattered locations in the Rangitaiki River near Galatea. We also have the koaro, more often to be found in clear, swift, forested streams with lots of boulders but probably much less widespread than before with the introduction of trout and common smelt to waters they did not previously inhabit. Adult koaro are also the main host for the freshwater mussel kakahi. Finally, there are three species of kokopu, the giant (*G. argenteus*), a particularly stout fish, banded (*G. fasciatus*) and shortjaw (*G. postvectis*); the largest giant kokopu weighed 2.8 kg and was 580 mm long! All three kokopu often feed on terrestrial invertebrates from the surface.

Mudfish (*Neochanna* species), of which there are two species in northern New Zealand, are also galaxiids; they live in swamps and other wetlands and all have either absent or very degenerate pelvic fins (we shall encounter them later). The burgundy or Northland mudfish (*N. heleios*) is rare but may be found in eastern Northland, including Lake Omapere; the black mudfish (*N. diversus*) is much more common, ranging from Kaitaia to the Mokau River in the west and the Hauraki Plains in the east, and is particularly common in Waikato wetlands. These fish can aestivate (lie dormant in hollows when water dries up) during dry springs and summer, breathing air through their skin.

BULLIES

The second largest group of fish are the bullies (family Eleotridae); they are often referred to as cockabullies but in fact differ from that mostly marine family. They are well camouflaged against rocks and sand and are an important predator, feeding on insects and crustaceans that live on the bottom (the 'substrate'); one often sees them darting about on the bottom in shallow waters. Common bullies, appropriately named since this is the most common species encountered and one of the few native fish that has not been significantly affected by our transformation of its environment, inhabits almost all freshwater environments from lakes to wetlands, especially slower waters. There is also the very similar (and only recently separated) Cran's bully (*Gobiomorphus basalis*), endemic to the North Island, which lives in inland streams and can reach high numbers in areas of good water quality. The colourful redfin bully (*G. huttoni*) lives in pools with stable rocks in forested, fast-flowing streams, again feeding on benthic invertebrates, mostly aquatic insect larvae living under rocks; because of habitat loss, these are more restricted in population. Being strictly diadromous (i.e. the larvae must be washed out to sea before coming back to freshwater as juveniles),

below **The redfin bully, *Gobiomorphus huttoni*. Photograph: Paddy Ryan.**

the redfin cannot establish landlocked populations whereas the Cran's bully is non-migratory and the common bully may be both migratory or landlocked. The bluegill bully (*G. hubbsi*) lives in swiftly flowing waters of gravelly streams near the coast, the same environment as torrentfish (*Cheimarrichthys fosteri*), albeit at the edge of the turbulent white-water areas preferred by this other fish; they are particularly common in braided rivers. Finally, there is the giant bully (*G. gobioides*) which can grow to more than 15 cm long. A coastal-area fish, it is mainly found in estuaries and the lowest reaches of rivers and streams, just above low tide, right around New Zealand.

EELS

The biggest (and, to little children, probably also the scariest) of our native fish are eels. The longfin eel (*Anguilla diefenbachii*), present almost everywhere and a skilled climber when small, is the largest — adult females can be up to 30 kg and 2 m long, the heaviest freshwater eel in the world. Females of all our eel species grow bigger than their male counterparts; the male only reaches about 70 cm. One has also been recorded as reaching 106 years of age. When they get larger, at about 40 cm, they generally turn from feeding on invertebrates to eating other fish and even birds. The other most well-known native eel is the shortfin (*A. australis*), also widespread; over the last 20 years, the spotted eel (*A. reinhardtii*), previously known across the Tasman in Australia, Lord Howe Island and New Caledonia, has also taken up residence on our shores.

Native eels are catadromous — they live in freshwater but migrate to the sea to breed when they reach sexual maturity at the very end of their life. Shortfin eels migrate to the seas around New Caledonia, eastern Australia and the Fiji Basin, the landmasses of which we share our population with; the longfins probably migrate to around Tonga. They die in the place they migrate to but the juveniles then re-enter the inland waterways.

left **Freshwater longfin eels, *Anguilla dieffenbachia*, Tutaematai, Whangarei District. Photograph: Simon Franicevic.**

OTHER FRESHWATER FISH

A common intermediary in the food chain between limnetic invertebrates and introduced trout is the New Zealand smelt, also known as the New Zealand cucumber fish and the New Zealand common smelt (to distinguish it from another in Canterbury). A silvery fish, it is about 8–13 cm long and lives in the upper part of the water column. It is the only smelt species in the north, often found as shoals in estuaries, some lakes and lowland rivers and often abundant, being the main herbivorous fish in most of our larger lakes and preyed upon in turn by the introduced salmonids (mainly rainbow trout). Although most smelt spend the majority of their lifecycle at sea, juveniles come inland in spring. However, some live in our central landlocked lakes, having abandoned the marine adult phase.

Other native fish include the torrentfish, which lives in flowing torrents and also spends part of its life at sea, as does our one species of lamprey (*Geotria australis*), a primitive, parasitic fish which migrates upriver in winter and spring and spawns in the headwaters of small bush streams, living there for a few years and then migrating out to sea (anadromous). The black flounder (*Rhombosolea retiaria*) does the opposite, spawning at sea but spending most of its life in rivers or lowland lakes.

We used to have one more freshwater fish, the grayling or upokororo (*Prototroctes oxyrhynchus*), a close relative of the smelt and no relation of the Northern Hemisphere's grayling, which grew from 20 cm up to about 45 cm. Unfortunately, the last one became extinct in the 1930s. Uniquely among our native fish, it may have been able to eat living plant material.

DIADROMY

The careful reader will have noted from the above that a number of our freshwater fish (18 species, or about half) typically spend part of their lifecycle at sea, i.e. they are diadromous. This is a much higher percentage than is found in most continental landmasses. Our fish also tend not to be as tied to their river of origin as, say, the salmon of North America; this probably helps them to disperse more widely around our country and to become re-established after significant geographical changes such as the sea-level rise at the end of the last Pleistocene and geological trauma (volcanoes and earthquakes).

As also alluded to, some normally diadromous species may become landlocked, abandoning their marine stage and spending all their lifecycle in freshwater; this isolation from others may then lead to the development of new species (speciation). Koaro, common smelt and common bullies in particular are highly 'facultative' — they are usually diadromous but often abandon this lifestyle. All three are therefore often the most common fish in lakes at high elevations; koaro is notable for its ability to climb almost vertically. Banded and giant kokopu as well as inanga may also occasionally become landlocked. Of particular note is the dune lake galaxiid (*Galaxias gracilis*); it has diverged sufficiently from inanga over about 5000 years of living in western Northland's dune lakes (such as the Kai Iwi lakes) that it is now a different species; it is the only native fish confined to lakes in the north.

INTRODUCED FISH

Introduced fish include rainbow trout and, less commonly in the north, brown trout (*Salmo trutta*) which have made places like Lake Taupo famous among anglers; they were introduced particularly for the purposes of angling and eating, as our native fish, small and nocturnal as they tend to be, are not well regarded for either, with the exception

perhaps of whitebait fritters. Trout predate native fish such as smelt, koaro and bullies, as well as terrestrial and aerial invertebrates that wander too close to the water's edge and aquatic invertebrates; their predation pressure on aquatic herbivores may have changed the whole dynamic of the ecosystem in some parts of the country and the decline of koaro is probably due to their predation. Common smelt have even been introduced to lakes (e.g. Lake Rotopounamu) for the trout to predate, as they seem to withstand trout predation better. Carp (*Cyprinus* species) have been introduced to certain areas to control weeds, as they can eat living plant material; European carp (*C. carpio*), however, have been blacklisted as a noxious pest. Other introduced fish include tench (*Tinca tinca*), perch (*Perca fluviatilis*), rudd (*Scardinius erythrophthalmus*), goldfish (*Carassius auratus*), brown bullhead catfish (*Ameiurus nebulosus*) and koi carp (an ornamental strain of *C. carpio*), this last particularly in the Waikato.

Not only have there been overseas introductions but many of the dune lakes probably had no fish in pre-human times and had native galaxiids introduced into them by early Maori.

MARINE FISH IN FRESHWATER

A significant number of estuarine fish may also be found in freshwater environments, or at least the lower reaches of such, including the above-mentioned grey mullet as well as occasionally the stargazer (*Leptoscopus macropygus*) and yellowbelly flounder (*Rhombosolea leporina*). The dart goby (*Parioglossus marginalis*) has been found in streams on Great Barrier Island and in North Cape since 2000; it is also known in Australia and is perhaps also a recent 'marine wanderer'.

BIRDS

When we look at any lake, pond or river, perhaps the most obvious animals are the birds, being both big and visible on the surface; and of the birds, ducks are surely the most prominent. Northern New Zealand has several native species of duck, two of which are endangered — the whio or blue duck (*Hymenolaimus malacorhynchos*), which lives in the headwaters of streams in the less-modified Te Urewera, East Cape and central North Island regions, as well as the South Island's West Coast; and the brown teal or pateke (*Anas chlorotis*). Pateke had been reduced to only a few locations: in the north, Mimiwhangata and Whananaki in Northland and Little Barrier and Great Barrier islands in Auckland. However, it has since been re-introduced to the Bay of Islands, Tutukaka, Auckland's Tawharanui Regional Park, the Coromandel, and Tiritiri Matangi and Mayor islands; its numbers would seem to be increasing. Its fatal flaw, like other New Zealand natives, is that it freezes rather than flies when it senses danger.

Other native ducks are somewhat more common, such as our smallest flying duck, the grey teal or tete (*Anas gracilis*), which may be found in freshwater and surrounding wetlands as well as estuaries; they are also found in the South Island, New Caledonia, New Guinea and Australia, whence come regular newcomers. Not to be confused with it is the grey duck (*A. superciliosa*), which may hybridise with the introduced mallard (*A. platyrhynchos*), the latter being now our most common duck. We also have the endemic New Zealand scaup (*Aythya novaeseelandiae*), a diving duck preferring the larger lakes, and the New Zealand shoveler (*Anas rhynchotis variegata*) which, as well as being found on lakes and in wetlands, may also be seen on sewage ponds!

The black swan (*Cygnus atratus*), a species once extinct in New Zealand, has now

top **A resting brown teal. Tiritiri Matangi Island, Auckland.**

bottom **Black swans (*Cygnus atratus*), near the Kopuatai Peat Dome. Hauraki District.**

returned thanks to its survival in Australia and is not uncommon, as are three species of geese (Anserini tribe of the family Anatidae), all introduced. Ducks and swans are generally ‘dabble-feeders’ — they feed as they float on open water or on nearby terrestrial vegetation such as saltmarshes and pasture.

Other birds specialise in different areas, i.e. they fill different ecological niches. Blue ducks are the only birds that specialise in feeding in white-water torrents, where their main prey are insects. Others birds, including wrybills (*Anarhynchus frontalis*), plovers (*Charadruis* species) and sandpipers (*Calidris* species) are termed shallow-water waders. They have short legs and hence feed mainly in water less than 40 mm deep (e.g. braided rivers); birds with longer legs, such as stilts (*Himantopus* species), herons (*Ardea* and *Egretta* species) and oystercatchers (*Haematopus* species), can feed in over 200 mm. Godwits (*Limosa* species) and other Arctic-breeding birds which migrate here in summer to escape the Arctic winter feed in similar environments, although usually in estuaries and around the coast rather than in freshwater.

The New Zealand dabchick or grebe (*Poliocephalus rufopectus*) is a diving bird of

open water, feeding on insects and their larvae as well as molluscs such as snails; sometimes they also tackle larger prey such as crayfish and fish. It is a 'Nationally Vulnerable' species, but still present in the far-north lakes of Omapere, Owhareiti and Kereta as well as the Matata Lagoon and the Rotorua lakes of the Bay of Plenty; very similar is the Australasian little grebe (*Tachybaptus novaehollandiae*), also found in the same three far-north lakes.

New Zealand scaup (*Aythya novaeseelandiae*) and cormorants and shags (family *Phalacrocoracidae*) also feed on invertebrates living in our larger, open bodies of water, either in the water column or on the bottom, and are hence termed open-water divers.

Gulls and terns (family Laridae) are aerial hunters, diving for invertebrates and small fish from the air; gulls in particular are aggressive scavengers and have adapted well to European changes to New Zealand, scavenging in urban areas among refuse as well as on pastureland, hunting invertebrates. The black-billed gull (*Chroicocephalus bulleri*, also known as Buller's gull) is the most common such bird found in freshwater habitats, as the others tend to be more coastal. However, the red-billed gull (*Chroicocephalus scopulinus*; until recently it was thought to be the same as the Australian *Larus novaehollandiae*) is particularly common around Lake Rotorua as well as in towns, and the southern black-backed or kelp gull (*Larus dominicanus*), our largest gull, can also be seen inland. Shags such as the little black shag (*Phalacrocorax sulcirostris*), the little shag (*P. melanoleucos*) and the black shag (*P. carbo*) can also breed inland.

Finally, rails, such as pukeko (*Porphyrio porphyrio*) and marsh crakes (*Porzana pusilla*), and bitterns (matuku-hurepo, *Botaurus poiciloptilus*) are swamp specialists but can often also be seen along the swampy margins of rivers where they feed on seeds, vegetation and invertebrates; in the bittern's case, fish and amphibians also form part of its diet. There are also some birds that are often seen around waterways but are not dependent on them, such as swallows (family Hirudinidae), pipits (*Anthus* species) and kingfishers (in the order Coraciiformes).

left **A female mallard duck and a black-billed gull on the shores of Lake Taupo, Taupo District.**

FRESHWATER ECOLOGY

The fauna, both herbivores and predators, provides an important check on the population of both the flora and the other fauna; any disruption, for instance the removal of a predator, may have a ripple effect on the overall ecology of a body of freshwater. For instance, invertebrates, particularly the snail *P. antipodarum* (often the most abundant animal in our lakes and rivers), as well as caddisfly and mayfly larvae graze up plankton and periphyton, keeping that population in check, with snails being more important in quiet reaches and mayfly larvae in disturbance-prone streams. Trout tend to feed on these invertebrate herbivores more ferociously than do native fish, which may reduce the grazing pressure on periphyton and plankton and allow it to grow more rapidly.

EUTROPHICATION

Eutrophication, sedimentation and a resultant gradual decline in the flora and fauna of our lakes has, unfortunately, become the sad fate of many of our lowland lakes today. Eutrophication, or the response of an aquatic ecosystem to additional nutrients (nitrogen and phosphorus), is the main cause of degraded freshwater bodies both in northern New Zealand and worldwide. The sources of the additional nutrients that lead to eutrophication may include the following.

1. Land clearance on the surrounding higher ground. This:

- leads to increased nutrient run-off from farmlands into lakes and wetlands, particularly after rain
- reduces shade, increasing the light available for photosynthesis (relevant for small bodies of water only)
- removes littoral plants that help absorb nutrients from the water.

2. Farming effluent run-off; in particular, the current hot topic is dairy effluent run-off.

3. Sewage discharge into lakes; the city of Rotorua used to discharge sewage to Lake Rotorua until the late 1980s.

4. Septic tanks leaking into groundwater and then into lakes.

Introduced species have further changed the balance of our freshwater ecosystems and may compound the problem. For instance, the introduction of trout has altered the grazing pressure on plants, as previously mentioned, and some invasive species, such as *Egeria*, can grow so rapidly that they run out of nutrients. Large amounts of vegetation then suddenly die, once again leading to a sudden surge of nutrients.

Although many of these problems can be addressed, nutrient-rich groundwater may still take decades to reach its destination and hence the problem can persist. However, solutions include riparian planting and retirement from agriculture, forestry replacing pastoral agriculture on the surrounding land, sewerage reticulation and the establishment of wetlands (to suck up nutrients) surrounding lakes such as the Rotorua lakes. Other solutions may include diverting eutrophic water away from at-risk lakes, water treatments and chemical

A LAKE FOOD WEB

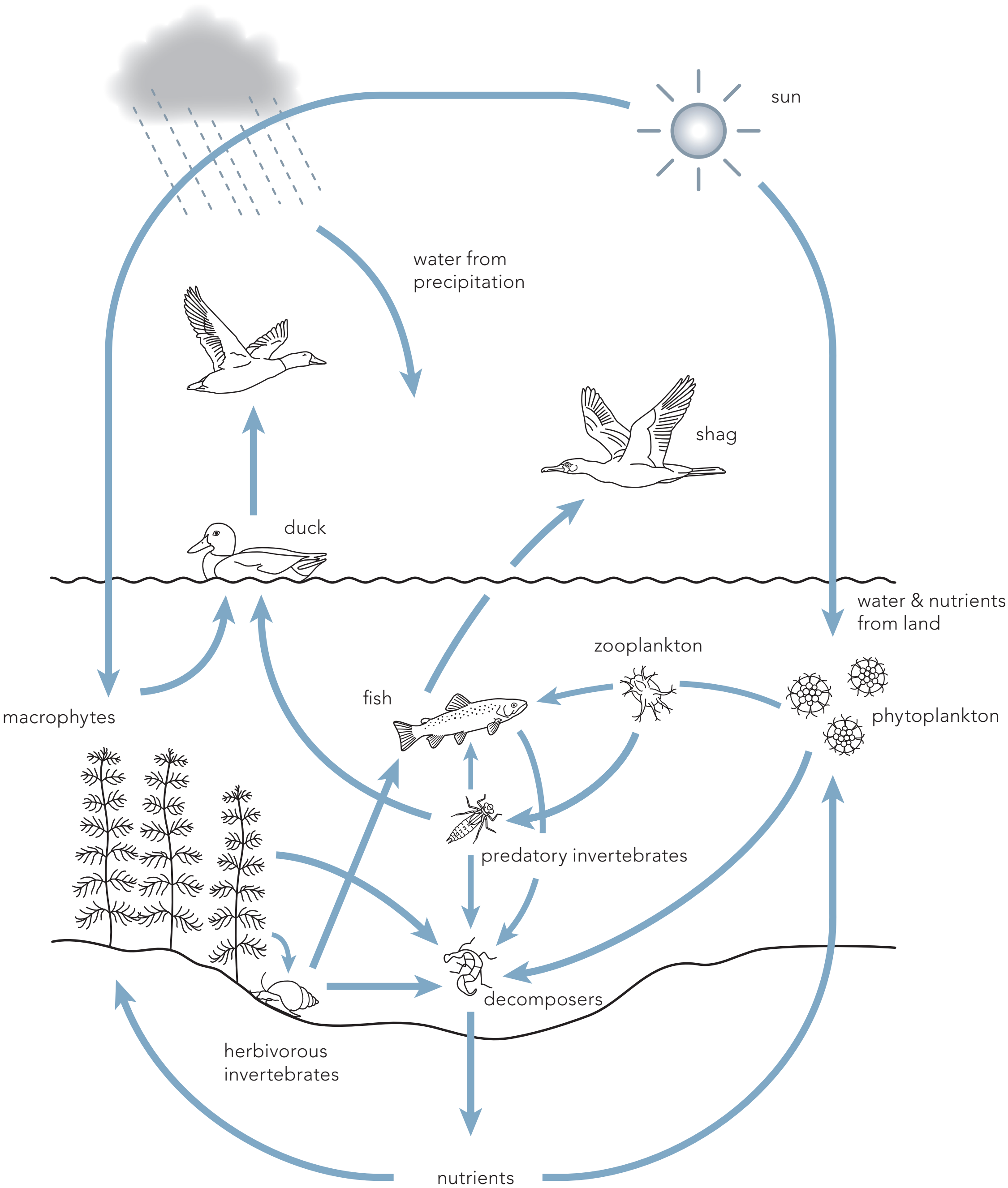


Figure 3 **A lake food web.**

above **Lake Waikare at sunset — a beautiful view, but not such a fantastic place to swim. Waikato District.**

solutions to reduce nutrients.

But how does the ecosystem respond to increased nutrition and why is it so bad? Normally the build-up of phytoplankton is limited by the available nutrients in the lake; once all the nutrients in the lake are used up, no more can appear. However, increased nutrient levels can lead to an excess of plant material, in the form of algal blooms and weed growth. Usually an algal bloom is of only one or a small number of species of phytoplankton (algae or blue-green algae/cyanobacteria), but those species reach concentrations of up to millions of cells per millilitre. The sheer amount of algae present in the water then cuts off light to species below and, when they die, the bacteria feeding on them use up the available oxygen in the freshwater, causing anoxia (lack of oxygen in the lake) and leads to the death of the lake's other inhabitants. This may lead to the release of phosphorus from bottom sediments, adding to the nutrient levels in the lake, which can in turn trigger more blooms. The bright green blooms most commonly seen are from cyanobacteria such as *Microcystis*; the term 'harmful algal bloom' (HAB) is used to describe those blooms that harm other species directly by mechanisms such as the production of natural toxins or mechanical damage; some species of cyanobacteria produce such toxins. These toxins may spread right up the food chain and even affect humans, making such lakes dangerous for us also (it should be noted, for interest, that the term 'red tide' is used to describe HABs in marine areas where the usual culprits are dinoflagellates, which are often red or brown).

Many of the shallow Waikato lakes

above **The eutrophic Lake Omapere: note the pasture right to the lake edge. Far North District.**

have been very seriously affected by eutrophication; the largest, Lake Waikare, is so enriched that it is termed a hyper-eutrophic lake. Its sad demise began when it was lowered by a metre in 1961, to 5.5 to 6.5 m, as part of the Lower Waikato-Waipa Flood Control Scheme. Then, in 1968, a severe storm ripped the weed off the bottom of the shallow lake, putting it into suspension and raising nutrient levels. Following this disaster it has not been able to recover, as it remains shallow and is continually fed nutrients from surrounding farm run-off and discharge from the Te Kauwhata wastewater treatment ponds, which has allowed blue-green algae to take over. The eels are much diminished as they can't get past the flood protection works, as are the shrimps, and in have come introduced koi carp. The adjacent Whangamarino wetland has been similarly afflicted by drainage and, when the control gates from Waikare are opened to allow water to pour straight down an artificial drain into the fen, is now prone to sudden floods. Crack willow, and more recently the even worse grey willow (*Salix cinerea*, introduced in 1925), in Whangamarino are supplied with nutrients from the eutrophic Lake Waikare as well as run-off from surrounding farms. Despite all this, Lake Waikare and the Whangamarino still work for us by taking water off the Waikato River when in flood, preventing the flooding of farmland, and earning money from gamebird licences.

Restoration of Lake Waikare is going to be difficult. The amount of wetland around the lake has declined by 67% since 1963, meaning less filtering of the nutrient load entering the lake. If larger plants were to become re-established this would decrease nutrient and suspended sediment loads by stabilising the sediments, but the suspended sediment currently restricts the light available to aquatic vegetation and high wind exposure promotes an unconsolidated lake bed. Further, were *E. densa* to become the dominant large plant and then collapse, releasing nutrients and sediments, it would start the cycle again.

Lake Omapere, the largest lake north of Auckland, also faces similar problems —which have also occurred, at least in part, because not only is it a shallow lake surrounded by agricultural lands (and hence nutrient run-off), but also because the lake level was lowered about 4–6 feet (1.2–1.6 m) in 1921. In that lake, which suffered an algal bloom in 1985, silver carp (*Hypophthalmichthys molitrix*) were introduced to try to control the algae. By 1996 *E. densa* covered 50% of the lake floor but then, overgrowing itself, proceeded to collapse over two summers, killing freshwater mussels, which are important in filtering the water, in the process (by anoxia); this caused another cycle of eutrophication, with toxins produced by the cyanobacteria rendering the water undrinkable. Grass carp were then released and by 2004 there was no *E. densa* to be found. Hopefully, keeping the lake

devegetated for some time and maintaining control of *E. densa* will eventually enable this lake to be restored — but perhaps also establishing riparian vegetation as a buffer zone and limiting nutrient run-off from dairy farms will be required.

The Rotorua lakes, one of our tourism and scenic jewels, are also being affected by eutrophication; not perhaps as much as Lake Waikare, but enough that there have been changes in the communities living in them. Lake Okaro became anoxic during the 1970s (with devastating results on koura, which were eliminated, and finfish, which were severely reduced) and Lake Rotoiti had to be shut to swimming in the 2002/3 summer; it is also at risk of becoming anoxic in autumn due to high concentrations of toxic hydrogen sulfide, which has killed most of the fish and shellfish — and this is one of our favourite recreational lakes. Even the giant Lake Taupo is facing declining water quality — and the groundwater coming in that is affected by land use will take 30–50 years to catch up with any changes.

above **The clear waters of Lake Taharoa, the largest of the Kai Iwi lakes, a west coast dune lake surrounded predominantly by pine forests and without significant human modification. Even the white sandy bottom is visible in the shallows. Kaipara District.**

Lakes such as Waikaremoana, surrounded completely by native forest and with no nutrient-rich rivers or run-off entering them, have not suffered from this problem.

The Kai Iwi dune lakes north of Dargaville also remain oligotrophic and crystal-clear; there is little inflow or outflow and native aquatic vegetation (particularly charophytes) predominates. Furthermore, there is a substantial vegetative buffer around these lakes.

PALUSTRINE WETLANDS

Palustrine wetlands are those inland wetlands (as opposed to open-water lakes and ponds) that lack flowing water, are fresh (having ocean-derived salt concentrations of less than 0.05%) and are not tidal. The term derives from the Latin word *palus*, meaning marsh. Swamps, marshes and bogs are common and familiar, but some unusual wetland types are also found in the north, including geothermal and underground wetlands (discussed later). Palustrine wetlands share many similarities with the littoral fringe of open freshwater bodies.

WETLAND TYPE	NUTRIENT STATUS	SUBSTRATE	WATER FLOW	WATER TABLE	DRAINAGE	WETNESS
Swamp	High (groundwater and surface water)	Mineral and peat	Medium	Usually above the surface in places	Poor	Permanent
Fen	Medium (groundwater and rain)	Mainly peat	Slow to medium	Near the surface	Poor	Near-permanent
Bog	Low (rain)	Peat	Almost nil	Near the surface	Poor	Permanent
Marsh	High (groundwater and surface water)	Mineral	Medium to fast	Usually below the surface	Moderate to good	May be temporary
Ephemeral wetlands	Medium (groundwater and rain)	Mineral	Medium to fast	Varies above to below the surface	Moderate to good	Temporary (seasonal)
Seepage	Low to high (surface water and groundwater)	Any (peat, mineral or rock)	Medium to fast	Varies above to below the surface	Moderate to good	May be temporary
Gumland	Low (mainly rain)	Mineral or peat	Almost nil	Below the surface	Good	Near-permanent (bar summer droughts)

Figure 4 **A classification of palustrine wetlands.**

Wetlands are often a transient environment; they accumulate over time according to environmental conditions and disturbance and are dependent on water supply. The coast only assumed approximately its current position at the end of the last Pleistocene, when sea levels rose to their current height (a marine transgression); hence, coastal wetlands are only between 5 and 20 ka at the most. Many low-lying

wetlands develop from lakes in which, over thousands of years, sediment and vegetative matter accumulate, transforming them in turn into swamps, fens and raised bogs. If peat does not form, the wetland may in time become dry land by the accumulation of sediment gradually lifting the ground level; plants often play an important role in trapping sediment and, by changing the environment from an aquatic to a terrestrial one, water-loving plants gradually give way to the terrestrial.

Most angiosperms in wetlands are emergent plants, given the shallowness of the water; they also have to cope with anaerobic soils, just as they do in other lakes and rivers. Wetland soils tend to have either a high organic content (such as peat, i.e. organic matter that hasn't decomposed) or gley, mineralised soils in which waterlogging has reduced ferric ions in iron oxides to the ferrous state, giving them their characteristic blue-grey colour.

One of the most important factors that determines the composition of the biota of wetlands is the hydrology — the depth of the water, how much it fluctuates, how often it is inundated and the frequency and length of wet and dry cycles — since plants differ in their tolerance of flooding. For instance raupo, club rush (*Schoenoplectus tabernaemontani*) and tall spike rush (*Eleocharis sphacelata*) are the most flood-tolerant and therefore build up the most in deep, stable water; stagnant water results in decreased oxygenation and allows dead vegetation to build up rather than being decomposed, which fewer plants tolerate; and rapid, large fluctuations are poorly tolerated by most. The vegetation itself, as we will see in the section below on peatlands, may also, over time, alter the local hydrology — for instance, if it builds up into a bog from a swamp.

There are many different ways of classifying palustrine wetlands. Here I shall look first at those that involve the laying down of peat, followed by the non-peaty wetlands. However, one can also group together as 'ombrogenous' wetlands those such as bogs, gumlands and dune lakes which receive most of their water from nutrient-poor precipitation, as opposed to marshes, swamps, geothermal wetlands and seepages which are termed soligenous because they receive water input from groundwater or rivers, and these carry with them many more minerals, nutrients and sediments. Wetlands may also be classified by the dominant vegetation cover — whether that be forest, scrub, reeds (reeds being tall, erect herbs with unbranched leaves that are either hollow or have a spongy pith), rushes, algae, sedges and so forth.

PEATLANDS

Mires, or peatlands, are those palustrine wetlands that contain peat — vegetative material that is unable to be broken down because it remains waterlogged. This results in an anaerobic environment which excludes those organisms that would usually decompose such vegetation; as a result, peat builds up. The soils in these wetlands are acidic, especially in bogs which lack groundwater input, as the latter is somewhat alkaline. This acidity further limits decomposition, as does the lack of nutrient input in raised bogs. Peat may be formed by any vegetation, but most commonly in northern New Zealand the original plants were restiads (rush-like plants) and/or sphagnum moss. One can further subdivide peatlands into the following.

- Swamps. Representing the early stages of transformation of open water into peatlands, these form in depressions in the underlying terrain and have, at least seasonally, a thin covering of flowing surface water, derived

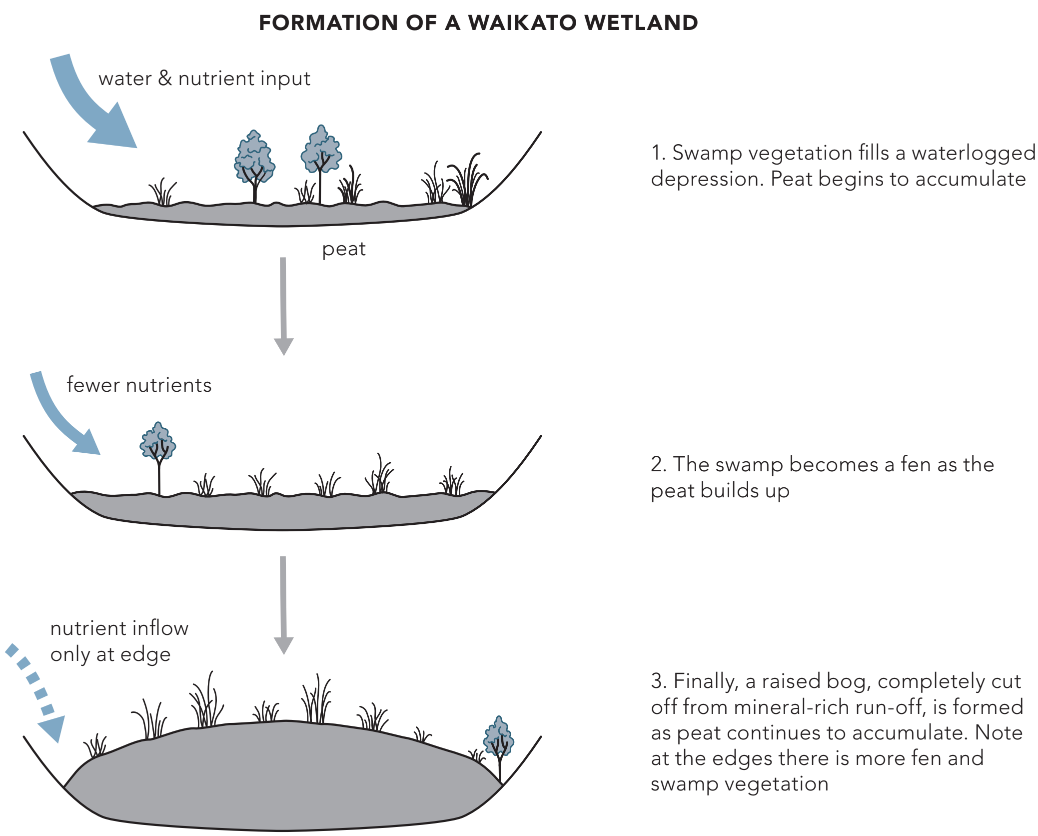
from groundwater or adjoining lakes and rivers, that carries with it nutrients from those environments. Some authorities also use the term 'swamp' to refer to non-peaty through-flowing marshes (fertile or eutrophic swamps) and oligotrophic, rain-fed infertile fens. Being flush with nutrients, in swamps light (along with water, competition, etc.) is a main factor limiting growth.

- Bogs, whose water comes only from precipitation because they are either raised or at least level with the surrounding land surface. Hence, they do not receive nutrient input from the surrounding land and water and are unable to support as rich a community as swamps. The Kopuatai Peat Dome — in the central part of the Hauraki Plains (renamed as such in the 20th century, being known as the Piako Swamp before it was drained) — is New Zealand's largest unmodified lowland wetland (except around the edges). It is a raised bog since its apex sits higher than the surrounding flat plains, and because of this it relies on mineral-poor precipitation for its water.

- Fens are the halfway house between swamps and bogs. These are level with the surface and receive some water and nutrients from the surrounding mineral soils. Our largest example is the Lower Waikato Basin's Whangamarino Fen, which lies in the depression formed by the surrounding rolling farmland and is fed by the waters of Lake Waikare.

These different categories represent a continuum; over time, swamps may gradually turn into bogs as they accumulate more peaty material, raising the level of the wetland above the surrounding land surface and thus cutting

Figure 5 **Formation of a peat bog.**



off the nutrient input. This continuum may also sometimes be seen all at the same site; one might find a eutrophic wet marsh around the outside of a peatland and a raised bog in the centre, distant from and lifted up above the groundwater.

All peatlands are acidic, bogs more so than fens and fens more so than swamps. The anaerobic conditions can lead to the accumulation of toxic gases such as hydrogen sulfide; when one sets foot in a peatland the ground often seems to deflate with each step, making a noise rather like an exhalation. Bogs, when raised above a flat surrounding land surface, are often dome-shaped, with the apex in the centre of the bog; although peatlands may also form on gently sloping ground, adopting either a uniform appearance (blanket mires) or one with distinct ridges and pools (string mires). The surface of a mire may often be covered by hummocks that form because the vegetation grows faster on the hummocks than in the waterlogged hollows.

OTHER WETLAND TYPES

Non-peatland freshwater wetlands are also very common in northern New Zealand. Marshes are wetlands that are better drained than swamps, usually because they are close to rivers or lakes (hence, the amount of water in them often also fluctuates); as a result, peat does not accumulate. Marshes may also be found in saline areas; in northern New Zealand, these are typified by the saltmarshes of our estuaries and are often vegetated by rushes, sedges, grass or herbs in a similar fashion to swamps. When the water table is lower than that required for a swamp or marsh one may instead find ephemeral wetlands; as the name implies, they are prone to drying out, particularly in summer; they tend to have no permanent outlet.

Other forms of wetlands include groundwater seepages and flushes, which are often surrounded by swamp-like vegetation, especially New Zealand flax (*Phormium tenax*). Gumlands, mentioned in Chapter 6, are also a type of wetland since their impervious soil horizon traps water in their acidic soil.

top **Inside the swampy gutter surrounding the much drier surface of the raised Opuatia Peat Bog (just visible in the background), dominated here by the introduced grey willow. Waikato District.**

bottom **Swampland beside Lake Taupo, near Turangi (the South Taupo Wetland). Note not only the native sedges, flax and manuka in the foreground (a less fertile part of the marsh, further from the lake), but also the invasive willows in the middle distance. Taupo District.**

left **A view over the Whangamarino Fen: note how it fills the low-lying part of the landscape and is surrounded by farmland and a rim of adventive crack and grey willows. Waikato District.**

THE VEGETATION OF MARSHES, SWAMPS, FENS AND BOGS

Unfortunately, the majority of our wetlands have been drained and converted to other uses, mainly agricultural, but swamps composed of reeds (reedlands) and raupo will still be familiar sights to most readers, common as they are around the borders of our lakes (as well as their saline cousins around our estuaries). Before drainage for agriculture commenced, we had many more lowland swamps in the hollow depressions of our land surface. It has been estimated that New Zealand has only 10% of its wetlands remaining, although in the Waikato (the north's low-lying, damp western interior) that percentage increases to 30%. Most occur either in former riverbeds, where sediment accumulated and eventually forced the river to change course, leaving behind a wetland, or at the edge of a river or lake.

THE VEGETATION OF SOLIGENOUS WETLANDS

The swamps and marshes that now survive are often surrounded by agricultural land with high levels of nutrient run-off, making them eutrophic (in a similar manner to open water), and have been heavily modified by invasion of adventive species. The predominant vegetation of such swamps (and seepages) tends to be monocotyledonous herbaceous plants (i.e. plants that die down close to the soil level at the end of the growing season and lack wood). They include:

- sedges, the most widespread of which are *Carex* species, including *C. secta*, *C. virgata*, loose clumps of *C. maorica* and *C. lessoniana* and the less-common denser tussocks of species such as *C. dissita*. Other sedges include *Cyperus ustulatus* which grows in dune hollows, estuaries and coastal flushes and, the largest, *Gahnia xanthocarpa* (mapere), which usually

grows in our warm forests. There are also the rush-like sedges, including *Machaerina juncea* and *M. articulata*, which prefer deeper water. *Schoenus carsei* is a threatened swamp sedge that prefers shallower water. Introduced sedges, including foreign species of *Cyperus*, may also be present

- true rushes (*Juncus* species), such as the native *J. edgariae* and the introduced *J. effusus*, which can even grow in well-drained pasture
- raupo, which is often dominant in our swamps
- the bur-reed *Sparganium subglobosum*, a relatively scarce emergent monocot that is also found in Australia
- the dicotyledonous New Zealand flax or harakeke, which prefers to be close to water channels (with more nutrients); it is vulnerable to grazing and competition from plants such as fescues, but tolerates fire and drainage. It is also commonly found around seepages
- other dicotyledonous herbs, uncommon in relatively unmodified swamps, which they may be abundant, especially introduced species in modified ones

left **Wetlands at Whatipu, Auckland. Many of the species mentioned in the text are visible in this part of the dune swamp, including cabbage trees, flax and various sedges; open waters (small dune lakes) are also visible in this view (the overlap with lakes and littoral vegetation is obvious; it would be equally justifiable to term this scene 'small dune lakes with a well-developed littoral fringe'!).**

right **An ephemeral wetland, the Waihora Lagoon, Pureora Forest Park, Ruapehu District. Fed by rainwater, this wetland is surrounded by swamp forest, predominantly kahikatea with swamp maire, pukatea, cabbage tree and pokaka as well as the occasional rimu. This photo was taken in September 2011; the lagoon dries up in summer.**

- mosses such as *Climacium dendroides*.

One may also find the orchid *Spiranthes novae-zelandiae* as well as toetoe (*Austroderia* species) flowering in spring, and the introduced pampas grasses (*Cortaderia* species) which flower in autumn; native grasses karetu (*Hierochloe redolens*) and *Isachne globosa* are also found in our swamps.

On drier ground we encounter woody trees and shrubs, including *Coprosma* species; manuka (often on drier ground bordering swamps); cabbage trees, which are particularly common after fire; and the introduced grey willow. Kahikatea-dominated swamp forest would once have also been common on all our flat alluvial plains, as it still is on the South

Island's West Coast. Remnants of this swamp forest can be found in places such as along the wetlands of the eastern shore of Lake Rotorua and on the more fertile edge of the Kopuatai Peat Dome as well as around wetlands in Te Urewera, the Raukumara Range and Pureora Forest Park; many more isolated remnants of such forest remain in drained wetlands that are now intensively farmed fertile alluvial plains such as the Waikato and Hauraki Plains and the Poverty Bay flats but, being dry, should perhaps be called 'ex-swamp' forest.

THE VEGETATION OF FENS AND BOGS

As peat builds up in a swamp, it lifts the wetland above sources of mineralised water inflow and thereby makes the swamp less fertile (oligotrophic), as already mentioned. It may now be termed a fen; manuka, tangle fern (*Gleichenia dicarpa*) and sedges such as *Machaerina teretifolia*, requiring fewer nutrients, become more dominant. As mentioned, the largest example of this type of wetland in the north is the 7000-hectare Whangamarino Fen of the Lower Waikato Basin, which began to form 1750 years ago, after debris from the Taupo eruption dammed water in this low-lying area. It is still mostly in the fen stage; wire rush (*Empodisma minus*) occurs in places and it will eventually turn into a bog provided there are no further major disturbances. However, there are also places near rivers and streams, where fertility is higher, in which the more swampy species of *Coprosma* and harakeke are common. There is also a contrast between the deep waters, which contain reeds such as *Machaerina articulata*, and the shallower areas in which manuka, cabbage tree and harakeke are more commonly found. On those areas that are becoming more bog-like, species such as *M. teretifolia* and *M. rubuginosa* as well as manuka are becoming more common. Finally, there are also large areas, particularly around the margin, that are dominated by the adventive grey and crack willows, sometimes with some native remnants of *Machaerina*, harakeke and *Carex* in the understorey.

above **Inside a shallow portion of the Whangamarino Fen which is seasonally dry (as it is in this image, taken in a dry March 2013): sinky and sucky mud, sedges, manuka and flax. Waikato District.**

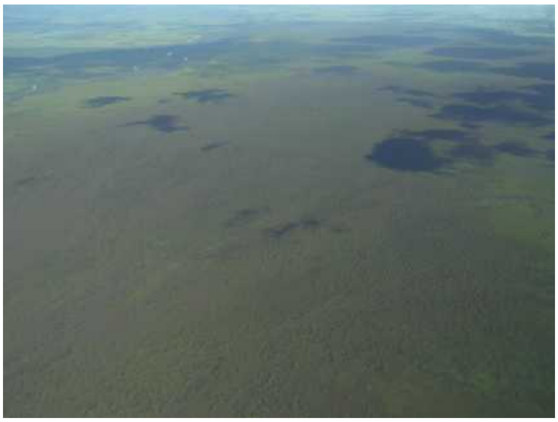
Such restiad fens and bogs, so-called because they contain peat derived from restiad species such as wire rush and cane rush rather than sphagnum moss, are unique to New Zealand. As well as Whangamarino and Kopuatai, there are other, smaller restiad wetlands, including Torehape-Pouarua in the Hauraki Plains and Opuatia (a peat bog surrounded by fen and swamp) adjacent to

above **Looking out over the just perceptibly domed surface of the relatively small Opuatia Peat Bog, Waikato District. Recently burnt and in the early stages of recovery from fire, this area of the dome is dominated by wire rush (*Empodisma minus*) with tangle fern visible around the base of the rushes, with occasional clumps of sphagnum moss (one is visible near the right margin). Grey willow is visible in the distance at the edge of the dome, in more swamp-like conditions with standing water present, whereas this raised surface is dry to stand on.**

Lake Whangape in the Lower Waikato Basin. Similar bogs and fens existed as far north as Kaitaia but are now very rare in Northland. Even in the boggier Waikato, many have been drained and converted into farmland. At a much higher altitude in Te Urewera, wire rush may also be found in the montane Kaipo Bog (sometimes called the Kaipo Lagoon, although the area of open water is the lesser by far), alongside more-montane species.

As the wire rush grows it creates a lot of peat, which raises the wetland above the level of the groundwater, making it reliant on rainwater and hence an acidic, infertile bog. Although bogs are drier than swamps, peat does contain water and hence the water table is brought up towards the surface of the dome; nevertheless, if one walks across it one's gumboots do not fill with water as they would in a swamp but instead stay dry, supported by the peat. As mentioned previously, the largest such bog is Kopuatai Peat Dome, on the Hauraki Plains, the southern end of which began to form at the end of the Pleistocene 13–14 ka, earlier than Whangamarino, and hence it has had longer to develop. At 8765 hectares it is also New Zealand's largest freshwater wetland and an internationally significant wetland under the Ramsar Convention. As a result of this change in environment another restiad, *Sporadanthus ferrugineus*, the tall, jointed, so-called giant wire or bamboo rush (a New Zealand endemic), becomes dominant over wire rush; it occupies about 2000 hectares at the centre of the dome where the water table is at or near the surface in summer and, where it is dense, excludes other plants. It is now almost only found in the Kopuatai Peat Dome (its main stronghold), the adjacent Torehape-Pouarua, currently being restored, and Moanatuatua in the Hamilton Basin. Other plants also found on peat domes include a small endemic shrub, *Epacris pauciflora*, and several threatened plants including a marsh fern (*Cyclosorus interruptus*), carnivorous bladderworts (*Utricularia* species), a clubmoss (*Lycopodiella serpentina*) and the red-bearded orchid (*Calochilus robertsonii)*.

However, surrounding the very infertile



top **Zonation at the edge of Kopuatai Peat Dome, Hauraki District. Note the kahikatea swamp forest in the upper left-hand corner; this gives way to manuka and then the fern *Gleichenia dicarpa*, the sedge *Machaerina teretifolia* and wire rush, on the fen-like periphery of the raised bog.**

bottom **The immense Kopuatai Peat Dome, a bog of the Hauraki Plains, Hauraki District (the black spots are the shadows of clouds). Note the brown central areas of the raised dome dominated by *Sporadanthus ferrugineus*; surrounding it are the other zones of vegetation described in the text that take hold as the environment gradually changes from an oligotrophic bog into a more mesotrophic fen and swamp.**

raised dome at the very centre are less-raised, more-nutrient-rich zones favouring different vegetation types; the distinction between bogs, fens and swamps is not absolute, as one grades into the other.

Surrounding the bamboo rush is a low community of the sedge *Schoenus brevifolius*, wire rush and the moss *Campylopus acuminatus*, presumably denoting a low-nutrient area. A combination of the sedge *M. teretifolia* and wire rush may be found on wetter ground and *Sphagnum falcatulum* grows in pools of water. In some areas there is a two-tiered structure with a canopy of manuka and bamboo rush and an understorey of wire rush and the sedges *M. teretifolia* and *S. brevifolius*.

Further out to the periphery is a drier zone of *Machaerina* and the fern *Gleichenia,* which then grades into dense manuka at the fringe of the dome where there is a more fen-like environment since the surface of the wetland at this point has not been lifted as high above the surrounding ground as in the centre and, as a result, there is a lot more nutrient inflow and conditions become much more mesotrophic. There is also, among the willow, a stand of kahikatea swamp forest near the edge of the dome; once this would have been a much more common border fringing the more-fertile edges of the bog.

The groundcover at Whangamarino and Kopuatai also includes mosses such as *Sphagnum cristatum*, liverworts (including *Marchantia berteroana*, which can be found colonising bare peat) and even carnivorous herbs (sundews (*Drosera* species) and bladderworts), which supplement the limited nutrients available in the wetland by digesting small invertebrates.

MONTANE PEATLANDS

Mountain peatlands also exist, containing different species again, such as the 'Ongarue A mire' of Clarkson near the summit of Mt Pureora which lies in a depression and feeds the headwaters of the Ongarue River. Predominantly a bog, with the rain the main source of water, it has an outer, better-drained marginal 'shrubland' zone of larger vegetation such as mountain toatoa (*Phyllocladus alpinus*), *Coprosma* species, manuka, *Dracophyllum subulatum* and bog

pine (*Halocarpus bidwillii*) as well as the moss *Sphagnum cristatum*, and an inner sedge–fernland zone, where there is no significant water flow, dominated by plants such as the square sedge (*Lepidosperma australe*), ferns, moss (*Dicranum robustum*), and particularly humps of tangle fern. Right in the middle, where the bog water drains and starts to become the Ongarue River, there is increased flow and it once more becomes a fen with ferns and *Sphagnum cristatum* moss.

The previously mentioned montane Kaipo Lagoon and surrounding bog in Te Urewera is also home to sphagnum moss, forming hummocks surrounded by pools of water, as well as wire rush and tangle fern; the vegetation in this bog has been used to study New Zealand's climate over the last 10 ka, since peat, by definition, does not decompose.

above **A mountain bog in a depression at 820 m above sea level in Pureora Forest Park (near the appropriately named Bog Inn Hut), Ruapehu District. It is a fen situated on sloping ground with a rim of surrounding water; in the distance, one can see podocarp–hardwood forest dominated (at this altitude) by tawheowheo (*Quintinia serrata*) and Hall's totara (*Podocarpus cunninghamanii*). Termed 'Ongarue A mire' by Clarkson.**

WETLAND FAUNA

Much of the wetland fauna is very similar to that around lakes and rivers, given the similarity of littoral to wetland vegetation.

The smallest inhabitants, the microbes and small invertebrates, include animals such as amoebae, rotifers, copepods ('the insects of the sea') and cladocerans (water fleas, an order of crustaceans); the diversity of the microscopic fauna tends to be less in the dry periods but has not been well studied to date. Of the larger invertebrates, dragonflies, damselflies and moths are common; in particular, the Larentinae moths often feed on specific herbs associated with damp areas.

Prominent fish species include the shortfin eel and inanga, which use both permanent and seasonally wet wetlands. In Maori and early European times, wetlands were considered a very important food source; the Whangamarino Fen was noted for its eels and birds (as well as used for its flax), and eels are still commercially harvested from the river (the Whangamarino) which runs through it. The giant kokopu is also common in swamps, especially where there is flax, raupo and other emergents. Mudfish can be considered specialist swamp-dwellers, including ephemeral waterways. They are well adapted to life in such transiently wet locations, being able to burrow into the damp mud if the wetland dries out and become dormant (aestivate) so that they use less oxygen than normal; when water once again floods the

area, they reactivate. Their sight is poor, as it is of less use in such dark waters, and they probably rely more on smell; their fins are shaped more like those of eels and they slither around obstacles in the underwater swamp. As mentioned previously, the Northland mudfish is only found in the oligotrophic wetlands in the vicinity of Kerikeri; more widespread, ranging from Northland to Waikato, is the black mudfish, an inhabitant of both gumlands and peatlands (e.g. Kopuatai and Whangamarino); in former times, both species probably inhabited forested wetlands also. Banded kokopu and the common bully are also not uncommon and, unfortunately, neither are the introduced koi carp nor gambusia *(Gambusia affinis*, formerly known as mosquito fish), the number one noxious fish of Auckland and the Waikato.

The only bird that is an obligate swamp resident is the insectivorous fernbird or matata (*Bowdleria punctata*), which prefers to live on the woody shrubs (usually manuka) which may form a scattered canopy over a lower level of sedges, wire rush and ferns growing on our acidic peat bogs; it is found only in New Zealand and we have the North Island subspecies. However, only small insectivores live on the bog, as it is not a rich environment.

Many small passerines also live in swamps, especially those with a lot of woody vegetation, such as the native fantail (*Rhipidua fuliginosa*), grey warbler (*Gerygone igata*) and (self-introduced) silvereye/waxeye (*Zosterops lateralis*) as well as the introduced yellowhammer (*Emberiza citrinella*) and chaffinch (*Fringilla coelebs*).

In areas with open water and more food sources, one encounters a wider range of birds. On the ground, among reeds and rushes, live rails such as the marsh crake, our smallest and most secretive crake; spotless crake (*Porzana tabuensis*); banded rail (*Rallus philippensis*); and pukeko. A recently arrived rail from across the Tasman is the Australasian coot (*Fulica atra*), another omnivore and a strong swimmer and diver. Rails have widely spaced, long toes which allow them to step on floating vegetation more easily and, together with a few other species including brown teal and the Australasian bittern, they can be considered true swamp specialists. The Whangamarino Fen is estimated to hold about 25% of New Zealand's Australasian bittern population, but unfortunately the once widespread New Zealand little bittern (*Ixobrychus novaezelandiae*) is now extinct.

Some ducks, including the native New Zealand shoveler (*Anas rynchotis variegata*) and the grey teal/tete, can also be found, not uncommonly, in wetlands. In fact, the paradise shelduck (*Tadorna variegata*) is most commonly found in wetlands and nearby pasture and is one of the few native species to have benefited from human settlement with the ensuing conversion of forest to pasture, where it can feed on grass, clover, seeds and grain.

Pukeko are perhaps the species most commonly encountered in our swamps and wet pastures. They are native but not endemic, as they occur in many other landmasses in our region, including Australia, which is probably where our pukeko originally came from. The pukeko's fossil record is in fact very limited and it is likely that they have only become settled here in numbers since widespread forest clearance began in the last few hundred years. In Australia, they are called 'purple swamp hens'. Like many swamp birds, pukeko are heavy with short wings and prefer to run and hide rather than fly; but, unlike its cousin the takahe (*P. hochstetteri*) which arrived from Australia much earlier, it still can fly, which is why it manages to survive on the mainland. It is an omnivore, eating reeds and swamp vegetation as well as invertebrates and frogs; in our modified environments it swaps over to

crops and grass grubs in paddocks, making it a common sight.

Other Australian wetland birds that are present in our fauna include the white-faced heron (*Ardea novaehollandiae*), Australian coot (*Fulica atra australis*), Australian little grebe (*Tachybaptus novaehollandiae*), hoary-headed grebe (*Poliocephalus poliocephalus*), welcome swallow (*Hirundo tahitica*), spur-winged plover (*Vanellus miles*), black-fronted dotterel (*Charadrius melanops*), royal spoonbill (*Platalea regia*) and Nankeen night heron (*Nycticorax caledonicus*). All are post-human colonists; the black swan was exterminated from New Zealand with the arrival of rats and humans but has re-introduced itself from Australia.

above **Pukeko, adult and three juveniles, near Hamilton Lake, Hamilton City.**

OTHER SIGNIFICANT WETLANDS

THE TONGARIRO DELTA

As the Tongariro River empties into Lake Taupo, at the very southernmost part of this book's area of interest, it forms the South Taupo Wetland, dropping its sediment load into the Tongariro delta. As it drains land that is mostly still clothed in native vegetation, its waters are relatively low in nutrients when compared, say, with rivers which drain dairy pasture, and the delta supports plants such as raupo, flax, cabbage trees, rushes, sedges, toetoe and manuka as well as exotic invaders such as willow.

THE KAIMAUMAU WETLAND

Kaimaumau, to the west of the Rangaunu Harbour in Northland, is a gumland wetland — a type of heath but also an infertile mire (i.e. bog). It is composed of alternating sand ridges and depressions filled with peat. The peat overlies a hard pan which makes it impossible for water to drain out or the groundwater to replenish the water in the wetland and, as a result, a huge raised bog has formed on top of it. In the summer, the shallow lakes on the surface are prone to drying out. Trees last lived here 30 ka, making it a very old wetland; the kauri gum from such wetlands was once a mainstay of the Northland economy, used in the manufacture of varnish. However, this wetland is threatened by the invasion of exotic species such as the Sydney golden wattle (*Acacia longifolia*), with each new fire in the wetland allowing more invasion. Nevertheless, the natives are here in numbers. In the deeper waters, impounded by sand dunes, *Machaerina juncea* predominates, with some

raupo and occasional cushions of sphagnum-supporting species such as manuka. Around the margins of areas of open water *M. juncea* is joined by other *Machaerina* species, such as *M. teretifolia*, which prefers the driest ground. Over drier peat, manuka presides over an understorey of species such as tangle fern and the sedges *Schoenus brevifolius* and *M. teretifolia*. Mounds may be covered by kanuka and bracken; similar species cover the leached sand ridges which interrupt the peat as well as more typical gumland species, such as dragon leaf (*Dracophyllum lessonianum*), *Pomaderris* (including *P. kumeraho*, gumdiggers' soap; one can mix the flowers with water to create a type of soap), *Cyathodes fraseri*, New Zealand daphne (*Pimelea prostrata*) and the sedges *Lepidosperma laterale* and *Morelotia affinis*.

top **The delta of the Tongariro River, gradually growing out into Lake Taupo. Note also the canal in the foreground, from the Tongariro Hydroelectric Power Scheme, and the crack willow lining the main watercourses. In between these channels is swamp vegetation, dominated by sedges, reeds and flax. Taupo District.**

bottom **On leached, drier ground in the Kaimaumau Wetland is gumland vegetation, with manuka and, underneath it, tangle fern. Dominating the foreground is a large hole (note the children and adult as a size comparison); note also the white colour of the E horizon. Far North District.**

UNUSUAL WETLANDS

TEMPERATE WET HEATHS

These areas of little or no peat, ultra-infertile soils and an impervious horizon include the gumlands of the north and frost flats. They are detailed in Chapter 6.

GEOTHERMAL WETLANDS

On a planetary scale this wetland type is very uncommon, although in Earth's younger days life probably started in environments very similar to these. Northern New Zealand, however, still has this environment in places and both the heat and the extreme mineral environments present make for a very different ecology.

Water here is returning up from deep inside the Earth and brings dissolved minerals containing iron, arsenic, boron, sodium, fluorine, chloride and silica as well as carbon

dioxide and hydrogen sulfide gases, in the form of geysers, mud pools, hot springs, gas vents and fumaroles; a greater volume of such solutes is possible in warmer than colder water. It may be acidic also, if it contains a lot of sulfides (e.g. at Waiotapu), further restricting the range of organisms that can tolerate it; for instance, cyanobacteria (blue-green algae) are almost completely absent from acidic springs.

Of all the plants, algae are most tolerant and are abundant if it is not too hot or acidic but multicellular plants can only tolerate up to around 37°C, so above this temperature micro-organisms dominate the environment. Unicellular fungi may also be found in such waters. Cyanobacteria can tolerate up to 60–65°C and anaerobic sulfur-metabolising Archaebacteria flourish at temperatures of 85–90°C in thermal waters; some can withstand temperatures of above 100°C (water can reach temperatures above 100°C if the surrounding pressure is greater than atmospheric, for instance at depth).

The most heat-tolerant group of animals is probably the insects, including midges, some shore flies (Ephydridae, which can tolerate up to 47°C) and water beetles, which are often found in waters ranging from 28°C to 38°C, along with the copepod *Paracyclops waiariki*.

As one moves away from the most extreme environments, mosses, lichens, liverworts and ferns start to be able to survive; the first angiosperm to be found is the kanuka, growing on the warmest ground as a low, prostrate shrub instead of a tree. Some warmer-climate species also exist here, such as clubmosses. Further away, where the soil is less warm but still acidic, one may also find other woody species such as manuka, monoao and mingimingi, detailed in Chapter 6.

below **Geothermal wetlands — the crater lake at White Island, Whakatane District. Note the green colour from algae.**

SUBTERRANEAN WETLANDS

Cave-dwellers, particularly found in northern New Zealand in the limestone of the Waitomo District, may be divided into three categories: trogloxenes, which will go into caves but don't dwell there permanently, such as frogs, eels and rats; troglophiles, which usually but not always live in caves, such as glow-worms; and troglobites, which cannot exist outside caves. These last tend to lose their eyesight — and even their eyes, in some species — and the other sensory organs, such as hairs and antennae, enlarge to compensate; the skin also becomes pale. The humidity is high and the environment relatively constant in terms of temperature and air circulation (which is usually reduced).

Inside a cave, of course, there can be no photosynthesis and therefore there are no green plants; of all photosynthesising organisms blue-green algae can dwell the furthest in, with liverworts, mosses and ferns further out before finally one goes outside into the forest. Still, nutrients flow in from outside the cave and a food chain builds up inside, with crustaceans and insect larvae on the bottom rung, bullies and freshwater crayfish in the middle, and eels on top. Glow-worms (see the section on freshwater fauna) are of course a well-known cave-dwelling predator, mainly of flying insects.

GROUNDWATER

Although rarely considered, at any one time about 80% of New Zealand's freshwater is underground. In northern New Zealand, this resource is replenished mostly from rainfall but also from rivers, and can be found in aquifers in permeable rocks, such as relatively young, less-consolidated sediments and volcanic deposits; it discharges at springs, into rivers and at the coast. It is also used by humans for irrigation, public and farm water supply as well as household use. The quality of the water, such as the hardness and the amount of solid material, is variable and depends on the substrate in which it is stored.

Some locations are more well-endowed with aquifers than others; our basement greywacke rocks tend not to be porous, except where faulting (which causes fractures within the rock) is present; hence the relative lack of accessible groundwater in places where this underlies the surface, for instance Waiheke Island. These regions do not soak up rain as much, and streams and other surface wetlands in these areas will tend to dry out more during dry periods. Conversely, our alluvial plains, including the Rangitaiki Plains, the Poverty Bay flats, the Tauranga and Hamilton basins and the Hauraki Plains, as well as many others,

above **The Blue Spring, source of the Waihou River (and of much of our bottled water), where groundwater surfaces at the base of the Kaimai Ranges near Putaruru, South Waikato District. Note the large numbers of macrophytes in the water, typical of such cold-water springs with a constant flow and relatively low temperature.**

hold water between their various alluvial layers and are very important in horticulture and agriculture; in the Waikato, 400 wells are drilled annually for this purpose. Water may also be found in volcanic deposits such as ignimbrite, especially in the central North Island around Tokoroa and Taupo. The fractured basaltic rocks of Kaikohe, Whangarei and Auckland also contain significant amounts of groundwater, as do the more recent sedimentary Waitemata and Te Kuiti Group rocks; Auckland's original water supplies came from springs in Western Springs and the Domain and water is still extracted from Onehunga. The sands of the lower Aupouri Peninsula hold yet another important reserve of groundwater, and dissolution of limestone by underground water has led to the formation of the karst landscape of the west Waikato, as already mentioned.

Finally, of course, groundwater can sometimes come out warm as it gets heated underground, either in fault systems or by magma, as covered in more detail in Chapter 1.

CHALLENGES

Since European settlement, rapid and often disastrous changes have been made to our lakes, rivers and wetlands. Many lakes and wetlands have been drained, often to make way for economically productive farmland, given that, almost by definition, the vast majority of wetlands occupy low-lying, flat and easily farmed land. New lakes, especially the hydro lakes of the Waikato, have also been created, thus altering the whole dynamics of our wetlands.

As mentioned previously, eutrophication, caused by increased nutrient input due often to run-off from surrounding farmland (the contentious issue at present being dairy farming), causes massive damage to the flora and fauna of our freshwater. Increased nutrient levels cause massive algal blooms in the phytoplankton, reducing light penetration and thereby killing native communities (the detritus of which then becomes more nutrients); in some cases the lakes become dominated by phytoplankton but are otherwise 'dead', as has happened to many of the lowland Waikato lakes. When the macroscopic vegetation is healthy, however, it can help suppress phytoplankton, for instance by providing a nursery for zooplankton, its major predator.

The widespread introduction and subsequent success of many exotic species has also meant that it is very rare to find a wetland without such invasive organisms.

The challenge, therefore, is not only to retain and hopefully regain our wetlands, but also to restore those that already exist to a healthy state of being.

CHAPTER NINE:

THE COAST

INTRODUCTION

For many young northern New Zealanders, the coast provides the first lessons in natural history. The rock pools and their inhabitants fascinate for hours, the pohutukawa provide shade from the midday sun, and the bedrock is often exposed in eroding cliffs and shore platforms, enabling us to see the building blocks of the land.

As we approach the coast from the forested interior, the vegetation begins to change (although, unfortunately, today it is rare to have a complete succession of mature native forest down to the sea). Large podocarps become scarce; then the remaining broadleaved coastal forest changes character. Particularly near exposed coasts, the taller forest becomes restricted to gullies with only smaller, hardier plants surviving on the more weatherbeaten and salt-sprayed ridges. Some trees, such as pohutukawa (*Metrosideros excelsa*) and ngaio (*Myoporum laetum*), are more resistant than others to the desiccating effects of salt in particular, and therefore become dominant near the coast. They are often present right up to the edge of the sea, particularly in more-sheltered spots. Mangroves (*Avicennia marina* subsp. *australasica*) go one step further, of course, growing below the high-water mark — and one flowering plant, seagrass (*Zostera* species), even manages to grow underwater.

right **Perhaps the highlight of the north — our beaches in summertime. This one is Cactus Bay on Waiheke Island, Auckland.**

VARIATION IN COASTAL COMMUNITIES: THE IMPACT OF THE ENVIRONMENT

Many variables determine the type of community that forms on the shore, including the amount of wave exposure, the morphology of the coast, the temperature of the water and the position on the shore in relation to the tides.

SHORE EXPOSURE

Wave exposure is an important determinant of coastal communities, not only because it helps shape the shore, as outlined below, but also because different organisms differ in their ability to hold fast in the face of such exposure; the amount of time exposed to the elements as well as the intensity of that exposure are both important. Shores which are open to the sea are, by their nature, more exposed to the waves of the ocean, while almost completely enclosed shores may be very sheltered. Also, given that our prevailing wind comes from the southwest, the west coast is more exposed more of the time than the east, although the east can bear the brunt of storms, including heavyweights such as ex-tropical cyclones which barrel in from the north and northeast.

COASTAL MORPHOLOGY

Clearly an important determinant of biological communities, since some animals are made to burrow in the sand while others hide under rocks, the form that the coast takes depends predominantly on the underlying geology and wave exposure. To recap from Chapter 1, much of the west coast is sandy, built up by the prevailing westerly winds and sediment-laden currents, although some of the rocky headlands of the west Waikato coast are made of harder Murihiku rocks, accompanied by softer Oligocene limestones. Somewhat earlier limestones are also found on the coast further north in western Northland, and there are isolated patches of hard volcanic rocks, such as the predominantly conglomerate Waitakere coast and the basalt lava flows of Maunganui Bluff. Greywacke (hardened sandstone) rocks of the Waipapa composite terrane form many of the headlands around the

below **The scenic coastline of Mayor Island. Soft shores (beaches) fill in the sheltered embayments, while the erosion-resistant, hard igneous rock of the headlands forms hard shores on the more exposed headlands. Western Bay of Plenty District.**

eastern coast of Northland, Auckland and the Coromandel Peninsula, although the inner Hauraki Gulf is dominated by the softer Waitemata Sandstones. More-recent volcanic rocks also form parts of this coastline, for instance the cemented breccia of Whangaroa, the volcanoes of eastern Northland, the Coromandel Peninsula and many of the islands off the east coast. The beaches of Little Barrier Island, an andesitic stratovolcano, are andesitic boulder beaches that have been eroded out of the rubbly breccia and carried down the side of the volcano by lahars. Further east are the beautiful sandy beaches of the Bay of Plenty, turning into smaller bays backed by Torlesse greywacke rocks as one heads east of Opotiki. Finally, as one rounds East Cape and proceeds down the east coast, one finds much softer, heavily eroded mudstone and sandstone coasts with headlands interspersed with wild, lonely beaches.

Our coastline is also blessed with many harbours, especially in the North Auckland Peninsula. Many of these were river valleys during the last glacial of the Pleistocene and were drowned as sea levels rose; the numerous sinuous estuaries flowing into them usually represent the paths of drowned tributary streams. Such drowned river valleys are called rias. These and other very sheltered waters may be high in sediment and less saline than the sea, if they have significant freshwater run-off. Enclosed shores that are almost completely landlocked are very sheltered, and the major construction agents are usually tidal rivers rather than waves. There are usually extensive mudflats and mangrove forests which trap sediment so that, over time, the level of the ground rises and what was once mangrove swamp becomes saltmarsh and eventually dry land.

The coast has only been forming since sea levels rose at the end of the Pleistocene, stabilising in their current position about 5000–7000 years ago, but that amount of time has been sufficient to alter our coastline. In the most exposed areas, such as the Poor Knights Islands, only solid rock is left, the softer sediments already having been eroded away; on the mainland, similar hard rock forms exposed promontories and headlands. When there are alternating softer and harder

top **The rugged coastline south of Ruatoria, Gisborne District. This is a land of very soft rocks, although still with embayments and headlands.**

bottom **The sheltered waterways of the Kaipara Harbour, our largest harbour. Note the mangroves at the southern end (left foreground) and the large dune barrier, broken by the harbour entrance, cutting the harbour off from the west coast. Auckland and Kaipara District.**

left **Extensive shore platforms, formed since sea levels rose to their current levels, surround Saddle Island. Auckland.**

right **The Chicken Islands (Marotere), offshore from Whangarei. Far from land, these islands have little sediment input and hence lack well-developed sandy beaches. Only the hard greywacke Waipapa basement rock from which they are made has ensured their survival from erosion.**

rocks, such as in a syncline, we get a series of embayments (where the softer rock has been eroded away) and promontories (the residual harder rocks).

The amount of erosion in the last 7000 years can be seen from the wave platforms around the base of cliffs; those made of relatively soft Waitemata Sandstone around eastern Auckland are receding at an average rate of 3–5 m/100 years, forming wide shore platforms; the rate depends on the amount of wave action they are exposed to. Most of the erosion is carried out just above the littoral fringe; the rock is alternately wetted by splash at high tide and dries out during low tides, causing it to crumble. The saturated nature of the soft rock on the platform itself retards erosion. Further out to sea, at the low-tide mark, there is often a sharp drop-off at the edge of the rocky platform, due to wave cutting and bio-erosion. Hard rocks are eroded less quickly, usually by crashing and surging waves which seek out joints in the rocks. They eventually open these joints, loosening large blocks of rock that then drop out, causing caves and guts to form.

Such shores are known as 'hard' (i.e. fixed) shores, as opposed to 'soft' (i.e. mobile) shores which are made up of loose particles (e.g. sandy beaches). Hard shores occur where the waves are sufficiently strong and the initial underwater slope sufficiently steep that the waves retain enough energy to carve a rock platform. When the slope is not sufficiently steep for the amount of wave energy available to carry sediment, derived either from land or the ocean and then carried along by currents and waves to be deposited on the shore, a soft shore will develop. Some shores may be a combination of hard and soft shores; for instance, a rocky cliff might descend into the waters of a harbour (a hard shore), but its bottom might be buried in sediment (a soft shore).

On islands far out from the mainland there are few sandy beaches — just rocky islets — as the sediment input is small and erosion is high.

above **Sand dunes at Mangawhai Heads, Kaipara District. The sand on this east coast beach has been gradually accumulating, being moved up from the south (at the left-hand edge of the picture); the estuary, unable to travel further north because of a rocky headland, keeps the sand hills from cutting the township completely off from the sea.**

right **West coast sand dunes, a soft shore, at Te Paki in the Far North District, bisected by a narrow strip of vegetation hugging a small stream down to the coast at Ninety Mile Beach; our very own miniature version of Egypt's Nile Valley! Far North District**

However, where sediment supply is sufficient, large amounts of sand may accumulate. One feature of our coastline are tombolos, bridges of sand which, over time, have connected former islands to the mainland. The largest tombolo is the Aupouri Peninsula, connecting the Kaitaia area with Cape Reinga and its surrounds (the former Te Paki Island). Smaller ones include the neighbouring Karikari Peninsula and the even smaller tombolo of Narrow Neck, which connects Devonport to the rest of Auckland's North Shore.

Sand can also move from one place to another by the process of longshore drift. Waves usually come inshore at an angle to the beach rather than straight on, often following currents and the depth contours of the seabed. Hence, there is a component of water movement up or down a shore that will move sand and other sediments away from some places and deposit them elsewhere. We humans put in groynes to control this process and stop sandy beaches from being washed along the shore. A very obvious example of such sand movement can be found at Whatipu; the sands here have been building up over the last 100 years as currents have gradually moved a large amount of sand northwards up the coast; this large dollop of sand may continue to travel northwards in the future, leaving Whatipu bare again but filling Piha in.

With decreasing wave exposure, the character of beaches changes, becoming less sandy and more muddy. In enclosed harbours, flat mudflats of very fine particles are common as the water is so still that even the finest silty sediments can drift down to the bottom and accumulate.

WATER TEMPERATURE

The temperature of the water also influences the flora and fauna; as one would expect, the water generally gets colder as one goes further south. The highest open-water temperatures occur in early February, around Waitangi weekend, with the lowest temperatures in late August; generally the water temperature follows the air temperature, with a lag of 2–4 weeks. In the far north, off Spirits Bay, the summer maximum is 20–23°C and the winter minimum 14–17°C. The temperature further down the coast, off the exposed Medlands Beach on the eastern coast of Great Barrier Island, is very similar, with a maximum around 20–23°C and a 13–16°C winter minimum; the East Auckland Current, coming across from Australia, warms our eastern shores down as far as East Cape. The waters slightly offshore, for instance at the Poor Knights Islands, are more directly in this current and, as a result, can be even warmer. The shallower, sheltered waters of the Hauraki Gulf can also warm up to around 23°C in summer; in the winter, the same waters might get as low as 12°C; the lowest recorded is 9°C.

At the latitude of Auckland, open-water sea-surface temperatures on the west coast are around 3°C colder than on the east (summer maximum 19–21°C, winter minimum 13–15°C at Piha), due to the colder north-flowing water originating in the Westland and D'Urville currents, which comes up from the south. This colder water dominates the west coast in summer to about as far north as the

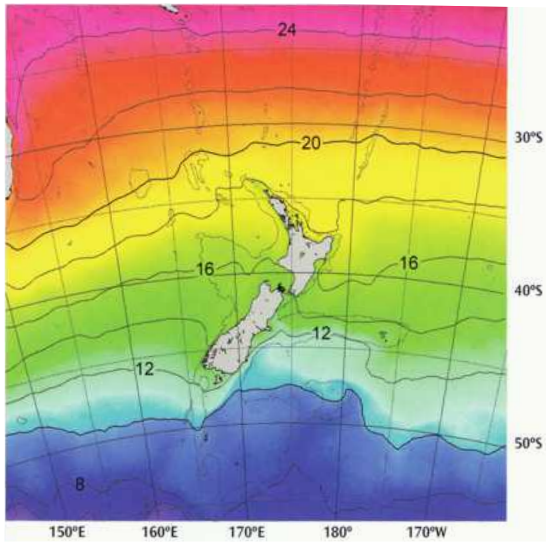


Figure 1. **Mean annual sea surface temperatures 1993–2002. Image reproduced courtesy of NIWA.**

Kaipara Heads, where it meets the warm West Auckland Current flowing down from North Cape. The West Auckland Current may reach further south in winter than in summer.

The East Auckland Current also warms the waters of the Bay of Plenty and East Cape, but further south, off Midway Beach in Gisborne, the water is cooler. There summer temperatures peak at 18–21°C on around 7 February and reach a minimum of 13–15°C around 23 August, as the coast of the Gisborne District is also bathed in northwards-flowing, cooler water (the Canterbury Current), which keeps the warmer water further offshore. Very similar temperatures exist at Raglan on the Waikato's west coast, peaking at 18–22°C around 9 February and reaching a minimum of 13–15°C on 21 August.

These temperature differences influence the biological communities of the shore such that we can divide the inhabitants of our region into the warm-temperate 'Aupourian' (or 'Auckland') Province, from approximately the Kaipara Heads (the exact boundary varies depending on the criteria used) around to East Cape, with the cooler 'Cookian' Province

further south. The Aupourian Province tends to have more mollusc species, with characteristic species including the black snail (*Nerita melanotragus*) and oysters of *Crassostrea* species, as opposed to the more southern black mussel, *Mytilus galloprovincialis planulatus* (although it is locally common in Auckland's Waitemata Harbour) and the ribbed mussel (*Aulacomya maoriana*). There are also characteristic kelp (algal) species such as *Psilophycus alveatus* and *Carpophyllum angustifolium* which are hardly ever found further south; conversely, *Durvillaea antarctica* is much less common in the warmer province except in very exposed locations, being much more prominent further south. Further, there are significant numbers of fish and other marine species that reach their southern limits at the boundaries of the Aupourian Province.

Right at the shoreline and in inner harbours the water temperature can vary widely, particularly after heavy rain or close to river mouths, where a lot of freshwater is discharged into the sea. Sustained offshore winds can also cause colder deep water to replace surface water that has been warmed by the sun. Smaller bodies of water can exhibit greater temperature extremes than these open-water temperatures; on 23 October 1949 (hardly the height of summer), a temperature of 38°C was recorded in a rock pool on Little Barrier Island, twice the sea temperature of 17.8°C; that day had a very low spring tide and the temperature around the brown algal holdfasts was 29.1°C; the plants were dying and rotting. This circumstance was probably due to a combination of low sea temperatures, high air temperatures and no wind, combined with an exceptionally low spring tide, exposing the holdfasts.

ZONATION

The other important factor in determining what lives where is how much exposure to either the air or the sea can be tolerated. As we go down from above the high-tide mark to below the level of low tide, we encounter zones where different communities thrive, depending on how much immersion in saltwater and exposure to dry air they are best suited to; this is called 'zonation'. Gradually, the types of species present change from the completely terrestrial, through those that can tolerate both wetting and drying, to the completely aquatic. One set of terms for these zones are the supralittoral, above the highest water level and so always in air; the sublittoral, always submerged; and the eulittoral, between the two extremes (littoral being another word for coast). The eulittoral can be further divided into the upper and lower eulittoral, either side of the mid-tide line. One can also speak of the adlittoral, that environment right next to the coast, such as where we might find pohutukawa and other elements of coastal forest.

On a sheltered shore, the supralittoral zone (and associated terrestrial organisms) comes right down to the spring high-tide mark (mean high water spring or MHWS); we are all familiar with the image of the pohutukawa tree in the quiet bay, its lower branches dangling in the water, or the grassy verge grading into the quiet saltmarsh or mangrove-choked estuary. As the shore becomes more exposed, with correspondingly larger waves and more salt spray — which may reach a lot higher than the waves themselves — maritime influences may affect communities well above the high-tide mark more and more, and the 'zones' become a lot wider. In such exposed locations, the lower eulittoral may contain more sublittoral communities as even at low tide, waves and surge keep these communities wet.

Another set of terms is the upper shore,

above **Zonation on a sheltered harbourside shore. Mangroves (and glasswort, *Salicornia australis*) merge into saline sedgeland with the tawny-coloured oioi (*Apodasmia similis*), the light brown *Juncus kraussii* (sea rush) and the less obvious (in this view) *Machearina juncea* (a sedge) and clubrush (*Isolepis nodosa*). Further up than this are scattered manuka (*Leptospermum scoparium*), marsh ribbonwood (*Plagianthus divaricatus*), flax (*Phormium tenax*) and New Zealand broom (*Carmichaelia* species), which gradually replace the sedgeland and are, in turn, replaced by kahikatea (*Podocarpus dacrydioides*) swamp forest (in the background). Eastern shore of the Whangateau Harbour, Auckland.**

above the mean high-tide mark; the lower shore, below the mean low-tide mark; and the middle shore, between the two.

In general, the harsher zones are the upper ones. Down at the bottom, where it is nearly always wet, the temperature is relatively constant (sea temperature), as is the salinity. However, as we go up the shore the temperatures fluctuate much more, as the exposed bedrock dries out and heats up in the summer sun, only to cool down again when submerged; and, as the water evaporates out of features such as rock pools higher up the shore, the salinity of the remaining water increases, which fewer species can tolerate. The upper shore is also exposed to longer periods of erosive wave action. As a result, the upper limit for species is usually determined by their tolerance of desiccation and extremes of environment; the lower limit, where more organisms can flourish in the more stable environment, is determined by how well they compete against the myriad other organisms which can also survive there. This includes both competitors for food and predators; for instance, Miller and Batt describe how if *Chamaesipho brunnea* (the brown surf barnacle) tries to establish at lower levels on moderately exposed western coasts, it gets overgrown by the smaller columnar barnacle (*C. columna*) and is subject to a higher level of predation by the more numerous carnivorous snails in that area.

SHORE ECOLOGY

As is also the case elsewhere, plants form the basis of coastal food chains, since they can manufacture organic molecules using water, carbon dioxide and sunlight. There is an interesting variation in the plant life of the intertidal zone: on rocky, exposed shores the algae (seaweeds), very simple plants, dominate and become more common as one goes deeper, whereas the 'higher', more-complex terrestrial plants, particularly angiosperms, dominate sheltered coasts, gradually encroaching into the water from the land with the last angiosperm present being seagrass.

All around the visible coastal community there is another, microscopic community, on which many of the food chains of the coast are based. The sea contains microscopic diatoms, plankton, bacteria algal spores and detritus, on which many of the filter-feeders such as barnacles and mussels depend, feeding when the tide is in. Some of this organic tide also ends up coating the various surfaces of the shores, including other living organisms (such as mangroves and algae), and is then grazed on by animals such as molluscs. Visible evidence of this food source can be found in the froth that swirls around our beaches after a storm. This froth results from organic molecules from decaying organisms, such as diatoms and algae, along with the microbes feeding on them, being blown ashore. The sea also provides a home for the young offspring of seashore residents, many of which, including molluscs, crustaceans and echinoderms, also spend the early phases of their life floating in the plankton before finally settling down on the shore.

The vast majority of animals that live on the shore are small invertebrates, mainly crustaceans such as sandhoppers (isopods and amphipods), barnacles and crabs; molluscs such as shellfish (bivalves), limpets, chitons, snails, nudibranchs and even octopi; or echinoderms (including starfish, sea urchins and brittlestars). There are also some unusual animals that do not look at all like animals, including sponges, anemones, ascidians (sea squirts) and bryozoans, that live on the coast. These animals are generally sessile (fixed in one place), although not always — our largest, the wandering anemone, travels quite long distances in the dark — and are relatively intolerant of desiccation, but they are animals and not dependent on sunlight. They can live in some unusual places; for instance, some anemones are attached by decorator crabs to their shells as a defence, and ascidians (sea squirts) can be found living on algae. Sea squirts are particularly interesting — they are actually a relatively close relative of vertebrates, having a notochord (the step before a backbone and still present, albeit in bits, in both you and I) when a juvenile, but regressing to a more 'primitive' form as an adult. Competition determines where various animals end up living; sponges, for instance, will often fail to find space in the wet parts of the shore when up against much-faster-growing algae but, being animals, they do not rely on light and therefore can often be found under boulders, in rocky crevices of rock pools and in other places both wet and shady. Worms are also common on the seashore; most of them are various types of bristleworm (polychaetes), characterised by their hairiness; many live in burrows or tubes ('tubeworms'), often on sandy shores, filter-feeding at one end

above **A polychaete worm. Jones Bay, Leigh, Auckland. Photograph: Simon Franicevic.**

of their habitation, although some are mobile carnivores.

Insects, although very common on land, are distinctly uncommon in any marine environment. One exception is marine caddisflies (Chathamiidae, which, bar one species shared with eastern Australia, *Philanisus plebeius*, are confined to New Zealand and the Chatham and Kermadec Islands; they are named after the Chatham Islands) of rock pools; another is the larvae and pupae of the mosquito *Opifex fuscus*, which develop in the stagnant waters of the upper shore under a swarm of adults. We also have two marine spiders. One, *Desis marina*, lives in cracks and crevices of the middle-shore harbour and comes out from its nest when the tide goes out, to feed on crustaceans. The other, *Amaurobioides maritima*, shares the same diet and also lives in similar cracks and crannies, but higher up the shore, in the splash zone.

FOOD ON THE SHORELINE

There are many different ways to sustain oneself on the shore. Niches that different organisms occupy include the following.

- Primary producers — those that make their own food from sunlight, water, carbon dioxide and inorganic compounds — include the macroscopic algae (seaweeds), as well as a coating on the shore rocks (i.e. an epilithic biofilm) of microalgae, cyanobacteria, spores and sporelings of macroalgae. The dominant organisms tend to be diatoms, filamentous green algae and algal sporelings. Living within this film are early-settling stages of invertebrates and bacteria. These biofilms are the main food source for intertidal herbivores.

- Herbivores may be divided into four groups, or guilds. The sweepers, such as topshells (Trochidae) sweep or brush particles from the rock surface. Neritidae are also sweepers, but they also have digging teeth, allowing them to excavate into rock. Rakers, e.g. winkles (Littorinidae), some grapsid crabs and small crustaceans, polychaetes, shrimps and some dipteran larvae, scrape algae from the rocks. Limpets, chitons and sea urchins use hard teeth to abrade and dig into rocks. Finally, fish and crabs of the family Majidae tend to be biters and cutters, mainly of the large green and red algae.

- Suspension-feeders primarily feed on plankton in the water column. On wave-exposed shores, the dominant species are barnacles and bivalves (especially mussels), as well as others such as some ascidians. Polychaete annelids are also suspension-feeders, often forming large colonies. Under a rock or overhang, hanging onto algae or even encrusting ships (here one thinks of the invasive *Watersipora*), one might find bryozoans, sponges (usually low down on the shore) and colonial ascidians.

above **A type of gastropod known as a helmet shell, *Semicassus pyrum*, usually a nocturnal predator of echinoderms, especially sea urchins. Jones Bay, Leigh, Auckland. Photograph: Simon Francevic.**

- Predators include those that live on the shore and those that merely visit, such as birds and fish. Perhaps the most common predators on rocky shores are the whelks, a type of gastropod mollusc, which include such genera as *Thais* and *Cominella*, that bore and drill their way into other shellfish. Crabs come out at low tide; most grapsid crabs are herbivores or omnivores but the other families of Portunidae (swimming crabs), Cancridae and Xanthidae (mud crabs) crack and crush the shells of their mollusc prey to get at the soft flesh underneath. Starfish, on the other hand, evert their stomach to engulf their prey and digest it in situ. Near the spring low-tide mark one might start to find other predators such as nudibranchs (a type of gastropod). There are also sessile predators, such as sea anemones and hydroids, which use their stinging cells (nematocysts) to stun prey.
- Parasites include both ectoparasites, living on the outside of animals (such as fish lice, an isopod), and endoparasites — for instance parasitic barnacles, trematodes and nematodes that may live in crabs, snails and larger organisms such as fish.
- Scavengers (detritivores or deposit-feeders) include animals such as amphipods and isopods that feed on the animal and plant remains washed up into the driftline with each high tide.

SOFT SHORES

BEACHES

We all have a mental picture of what a beach is, but there are many different types of beach. Perhaps that which the majority would imagine as an ideal beach is the sandy beach, such as the very exposed surf beaches of our west coast such as Raglan and Piha, and the slightly less exposed but equally excellent east coast beaches such as Mt Maunganui and Wainui. Muddy sandy beaches, typical of our harbours (such as Mission Bay and the other small bays of the Waitemata Harbour) are another favourite; they are less exposed and have a sloping sandy upper shore, but at low tide muddy flats make for a long walk out to get a decent swim. There are also pebbly beaches; they differ from sandy beaches in that the larger pebbles are found near the bottom of the beach as they tend to roll down, leaving the smaller ones stuck at the top, whereas in sandy beaches the large grains stay at the top of the shore, landed there by the swash of the wave, while the less powerful backwash removes the smaller grains to a lower level. On very sheltered shores, the beaches become flatter, more silty, and

above **Sheltered muddy sandy beaches of the indented eastern coastline of the North Auckland Peninsula. Urupukapuka Island, Bay of Islands, Far North District.**

dominated by terrestrial sediments, until eventually, in extreme shelter, there are just mudflats. The silty particles of mudflats are smaller than sand grains and, rather than dusting off easily, tend to stick to our skin; we find these places generally unpleasant, squishy and smelly (due to their anaerobic nature). Mudflats are the favoured realm of the mangrove and are not what most of us would consider a beach, although they are a type of soft shore. Finally, one can have beaches composed of boulders; Little Barrier Island is ringed with these.

The coast in general is not an easy environment in which to live and beaches, scoured by each passing wave and lacking a firm foothold for organisms such as seaweeds or sea anemones, are particularly difficult to live in. The instability of the surface means that only a small number of species may call it home but, because of reduced competition and predation, those that do are often very plentiful. The advantage of a beach over a rocky shore, however, is that one can burrow into it to avoid predators, drying out and battering by waves; when the tide is out, most inhabitants shelter below the surface, emerging again when the sea returns. How easy it is to live in a beach depends on the size of the particles, with smaller particles holding water better but reducing oxygen circulation. At a certain level in every beach, but closer to the surface in mudflats (with poorer oxygenation and larger organic inputs than regularly washed surf beaches) is a black layer of iron sulfide, where anaerobic breakdown of organic matter by bacteria has taken place.

Digging into the sand, one may find burrowing bivalve shellfish (a type of mollusc)

such as toheroa (*Paphies ventricosa*), tuatua (*P. subtriangulata*) and pipi (*P. australis*). Each favours a slightly different site — the toheroa lives in the upper shore of our very exposed western beaches, whereas tuatua and pipi live on the middle and lower shore — tuatua on the more-open, wave-swept and therefore lower-sediment shores and pipi in sheltered harbours and even brackish water. We may also find buried in quiet water (really in the tidal flats) beds of cockles (tuangi, *Austrovenus stutchburyi*), also a filter-feeding bivalve, as well as flies and earwigs. On small, solid outcrops of rock one might find the barnacle *Austrominius modestus* (a crustacean) and the little black mussel *Limnoperna pulex*; plants are represented by the microscopic diatoms and dinoflagellates.

There are also a couple of microhabitats that one may find on a sandy beach. One is the isolated boulder, which forms a miniature rocky shoreline, although abrasion by sand prevents some organisms attaching to it. The other is seaweed, often left strewn along the high-tide mark, which is then fed upon by small crustaceans (described below) as well as the black top shell (*Diloma nigerrima*).

Less-palatable fauna also inhabits our beaches; perhaps one of the most well known is the so-called 'Mount Mauler', a summertime biter of the Bay of Plenty and perhaps prevalent all along the east coast, that can leave you with a week of 'hell all over'. This particular specimen — the insect *Phycosecis limbata* — bites during the larval stage, November to February. However, as it lives in soft sand you are safe from it below the waterline.

Plants that grow next to the sea have to cope with a generally arid environment; sun and wind desiccate and sand is so porous that water just drains away. Furthermore, salt causes loss of water by osmosis. There are several ways of dealing with this. One is

top **An example of succulence are the thick leaves of this introduced South African ice plant (*Carpobrotus edulis*), in the centre of which is flowering another South African, purple groundsel (*Senecio elegans*), growing on sandy dunes at Ruakaka, Whangarei District.**

bottom **The waxy upper surface of the leaves of taupata (*Coprosma repens*) is an adaptation to cope with the coastal environment. Omaha, Auckland.**

through succulence — found in cacti and ice plants (*Carpobrotus* and *Disphyma*), whose leaves are bloated with water-storage cells; glassworts are also succulents. Not only can they store water, but the water reservoirs also act as a heat sink to control the plant's temperature, slowing down both warming and cooling. The introduced marram (*Ammophila arenaria*), conversely, protects its stomata

above **Our beloved moderately exposed beaches; the beautiful Mt Maunganui and Papamoa beaches, backed by dense suburbia. Tauranga City.**

(pores in the leaves for respiration, through which moisture can also be lost) within grooves on the bottom of the leaves, curling the leaves down into cylinders to further protect them when dry.

SANDY BEACHES

Beaches that are the favourites of many are those of the east coast of Northland, the Bay of Plenty or Gisborne District, which tend to be moderately exposed shores with a shallow-sloping, light-coloured sandy beach. Sand itself derives from local terrestrial sediments eroded down onto the beach, sediment washed up from the sea (often having been washed off the land by rivers and sometimes from deposits left when sea levels were lower, during the Pleistocene glacials) and the remains of organisms, such as diatoms and the broken shells of invertebrates, particularly bivalves, which may come from the beach or, like scallop shells, from further out to sea, coming ashore particularly during storms. The coralline algae also contribute to beach sand due to the calcium carbonate in their structures, and in more sheltered places we find banks of cockle shells. The squeakiest, whitest quartz sands derive mainly from the acidic rhyolitic volcanic rocks of the Taupo Volcanic Zone, washed down by the Waikato River (which used to flow out through the Firth of Thames). The whitest dunes of all are those of Kokota Spit at the entrance to Parengarenga Harbour in the Far North District; the sand there is everywhere more than 95% silica, the bulk derived from Podzol Soils. As the proportion of non-silica compounds increases, the sand gradually becomes less white. On the west coast are the well-known ironsand beaches; titanomagnetite (an iron oxide) derived from Mt Taranaki and more recent volcanic sediments brought down by the Waikato River gives them this colour. As the main source is to the south, the further north along the west coast we go the lighter the beaches become, as gradually magnetite becomes less common — it is most common (and mined) at Waikato North Head, Taharoa

and Waipipi and peters out at around the latitude of the Kaipara Harbour, where the northward-flowing Westland Current meets the southward-flowing West Auckland Current. On the east coast, the Hauraki Gulf sands include the same rhyolitic rock fragments that also bear witness to times when the Waikato River drained out through the Hauraki Plains; the beaches around Auckland's east coast also contain debris from eroded Waitemata Sandstone.

As the waves roll in, the largest particles of sand are dropped right at the top of the beach where the wave finally ends (the swash), but the smaller ones remain in suspension as the wave recedes (the backwash) and are deposited further down the beach, so that the beach sand becomes sorted into smaller grains at the bottom and larger ones at the top. This trend continues as we go further seaward and deeper, although in the deeper channels further out at sea, tidal scouring may remove the small, easily lifted sediment from their bottoms.

The sandy beach is zoned just as any coast, and crustaceans form the bulk of the animals. On the upper shore we might find the amphipod sandhopper *Bellorchestia quoyana* and the isopod sea slater *Scyphax ornatus*, which feed on the decaying plant and animal material left at the high-tide mark at night when the tide is going out, leaving wet sand, to avoid desiccation; they retreat into their burrows by day. The difference between these two types of crustacean, which we variously refer to by terms such as 'sea lice', 'sandhoppers' and 'fleas', are that isopods have a 'squashed' look, like slaters on land, whereas amphipods are sideways-flattened, like fleas, and tend to be more common on surf beaches. These small crustaceans, helped by others such as crabs, are very important scavengers of beach detritus and in turn feed larger animals. Further down in the middle part of the beach, that part regularly

top **A natural sandy beach. Te Werahi, Far North District.**

bottom **More-sheltered beaches line our harbours, such as at Opononi on the Hokianga Harbour, Far North District.**

covered and uncovered by all tides, neap and spring, we encounter smaller isopods and bivalves (clams), which burrow down into the sand and send up siphons to filter-feed on diatoms, plankton and organic debris when the tide is in. On sandy beaches the bivalves present include toheroa (*Paphies ventricosum*), which live on the upper shore of our very exposed western beaches, and

tuatua (*P. subtriangulatum*) living further down on slightly less-exposed beaches but where it is still wave-swept and relatively clear of sediment. The lower beach is only rarely exposed; characteristic inhabitants include the very small amphipods and the larger swimming crab (*Ovalipes catharus*).

Of larger animals there are generally few. One of the most commonly encountered is the oystercatcher, of which there are two types, the pied (*Haematopus finschi*) which is both black and white and breeds in the inland South Island, coming north to our coasts in winter to feed, and the variable (*H. unicolor*) which is almost entirely black and nests on our beaches. The New Zealand dotterel (*Charadrius obscurus*) can also be found breeding on our coastal beaches and dunes (and in the northern North Island; another population can also be found in Stewart Island — mainly above the treeline!), as can the banded dotterel (*C. bicinctus*).

Behind the beach, landward of the high spring tide, is the supralittoral zone. The border between the intertidal and supralittoral zones may be marked by drifted seaweed (the 'driftline') and associated annuals, all liable to be destroyed in the next storm or king tide. Here also begin the sand dunes, which are a result of the colonisation of sand dunes

top **Oystercatchers at Omaha Bay, Auckland.**

middle **The supralittoral zone of a sandy beach (Karekare Beach, Auckland). In the foreground is the beach itself (with black sand, being a west coast ironsand beach), while behind it is the supralittoral zone, with sand dunes colonised by the introduced light-green marram grass. Pohutukawa trees can be seen covering the rocky headland in the centre, at the start of the forest zone, with grasses, flax and other small herbaceous plants between the dunes and the trees. The vegetation has been stunted by the prevailing westerly winds and resultant salt spray driving up the valley on the left-hand side of the headland. In the distance, more typical forest covers the Waitakere Ranges.**

bottom **Pingao growing in sand dunes behind Ninety Mile Beach, Far North District.**

left
Muehlenbeckia complexa **smothers other coastal vegetation on the sandy dunes in the background, while grasses predominate in the slack. Near Omaio, Opotiki District.**

by plants, and which progressively become older and more stabilised by vegetation as one goes further inland. The first sand-binding plants to colonise and stabilise the dunes are usually the native spinifex (*Spinifex sericeus* — usually the most seaward) and pingao (*Ficinia spiralis*) as well as the introduced marram (*Ammophila arenaria*); this last often has fully displaced pingao in many beaches, due to its faster growth rate and rapid sand-trapping, although sand dunes bound by marram are more prone to blowouts in strong winds. Other pioneering plants include *Carex pumila*, the tussocks of the lower foredune *Poa billardierei* and shore bindweed (*Calystegia soldanella*), which grows from the bottom to the top of the foredune, along with several rhizomatous plants including bracken (*Pteridium esculentum*) and various grasses, both native and introduced. Another sand-binder, the spurge *Euphorbia glauca* is now rare, mostly growing on cliff ledges. Succulents such as *Cakile edentula* (sea rocket) and *C. maritima* are common in damp areas, as well as ice plants (including the native *Disphyma australe*), as are native tussocks (such as the sedges *Ficinia nodosa* and *Cyperus ustulatus*), our largest toetoe *Austroderia splendens* and non-succulent tap-rooted forbs (herbaceous flowering plants that are not grasses, sedges or rushes). Perennial weeds, fast-maturing and usually introduced, as well as low-growing native herbs, complete the picture. Lichens and bryophytes grow on stable surfaces, such as rock, with mosses and lichens becoming evident in the winter on open sand.

Further back than these pioneers, as humus accumulates — improving moisture-holding, increasing the available nutrients and binding the sand particles together — other species take over; *Muehlenbeckia complexa* often smothers older dunes, sometimes in association with the introduced kikuyu (*Pennisetum clandestinum*) and the nightshade (*Solanum linnaeanum*), the latter where the topsoil is deep, as well as introduced species such as blackberry, lupins and various garden escapees. Ironically, *Muehlenbeckia*'s ability to smother other vegetation is now causing problems on English shores, from whence came many of our invasive plants.

Microlaena stipoides is a common native

grass of dry flats, as are introduced grasses such as cocksfoot (*Dactylis glomerata*), *Sporobolus africanus*, *Axonopus affinis* and *Eragrostis brownii* as well as annual forbs. On the eastern side of the Aupouri Peninsula, native vegetation is still present on the dunes, including *Spinifex*, pingao, *Poa billardierei*, *Pimelia* aff. *arenaria* and *Coprosma acerosa*; in many other areas, marram is widespread all over the dunes. As the footing becomes stable, trees such as pohutukawa (*Metrosideros excelsa*), the coastal shrub daisy (*Olearia solandri*), *Dodonaea viscosa*, manuka (*Leptospermum scoparium*), tauhinu (*Ozothamnus leptophylla*), *Haloragis erecta*, *Solanum* species, and ngaio (*Myoporum laetum*) are also present, marking the start of the coastal (adlittoral) forest. Mahoe (*Melicytus ramiflorus*) and wineberry (*Aristotelia serrata*) come slightly later in sheltered spots or older dunes. Introduced species are also prominent, including the nitrogen-fixing tree lupin (*Lupinus arboreus*), gorse (*Ulex europaeus*), Monterey pine (*Pinus radiata*), elder (*Sambucus nigra*) and common broom (*Cytisus scoparius*). Where the water table intersects hollow depressions in the dunes we often find a line marked by the sedge *Carex pumila*. A wetland turf, eventually dominated by jointed wire rush/ oioi (*Apodasmia* (also *Leptocarpus*) *similis*), develops inside this line and, after 50 years, we often find the dominant vegetation has become the native toetoe (*Austroderia* species; three species in the northern North Island), pampas grass (*Cortaderia* species), cabbage trees (*Cordyline australis*) and, sometimes, manuka and coastal shrub daisy. Dune lakes (see Chapter 8) may accumulate in the slacks (a slack being the trough between dunes).

Blowouts caused by strong winds, especially from an unusual direction, can occur in partially fixed dunes which then need to be recolonised. Sands derived from shells contain calcareous material and are a source of lime for animals such as snails; in these areas a limestone-like vegetation can develop. However, on quartz-derived sands the nutrients of the shell fragments are leached out through the readily drained sandy soil by rain and this nutrient-poor, sun-stressed environment may develop a heathland vegetation, such as that on the Podzol Soils of the Aupouri Peninsula.

Finally, mention must be made of Monterey pine (*Pinus radiata*, from California), which has been extensively planted, especially on the west coast, to stabilise the dunes back from the sea. Ninety Mile Beach is almost a non-native landscape, with marram widespread on the foredunes, backed by pine trees, all stabilising the sand dunes and preventing the farmland on the eastern side of the Aupouri Peninsula from being smothered in sand; here, before the arrival of Maori and Europeans, native sand-binders and kauri forest would have achieved the same result.

MUDDY SANDY BEACHES

On more-sheltered (protected) shores, these beaches are common around many of our harbours — such as Mission Bay in the Waitemata Harbour. They have a sloping back of coarse sand and shell fragments heaped on the beach slope by the swash (still stronger than the backwash), and then a flat seaward extent of muddy sand that extends very shallowly for a long way, so that one has to wade out a considerable distance in order to swim at low tides; this is the upper limit of bivalve clams (indicators of the middle shore). The more sheltered a shore gets, the less steep, wider and finer the bank becomes, and the muddy sand inhabitants reach a higher level. There is still much standing water on the muddy sand, as in muddy shores, but there are enough coarse particles to aerate the soil

above **A muddy sandy beach at low tide. Snells Beach, Auckland.**

right **A muddy sandy beach at low tide, Karepiro Bay, Auckland. Note the sandy upper shore and the extensive mudflats on the lower shore.**

to about 30 cm and, being sheltered, it is a relatively stable place; so it is a very friendly environment with sufficient organic matter for the deposit-feeders, such as bristleworms.

On the upper shore one might find *Bellorchestia quoyana*, the sandhopper, as in more-exposed shores. Then, as we reach the flat top of the muddy sand, pipi can be found within the sand, feeding on detritus and phytoplankton in the sea. Further down live the cockle (*Austrovenus stutchburyi*) and a tellinid, the wedge shell *Macomona liliana*. Bristleworms such as the lugworm *Abarenicola affinis* are also found at this level, working their way through the mud on the hunt for organic material, as well as carnivorous bristleworms, eating other bristleworms as well as small crustaceans.

The whelk *Cominella adspersa* searches for sick cockles to eat and an olive snail, *Amalda australis*, is also present. Finally, the lower shore (between the neap and spring low tides) has the greatest diversity. Some common inhabitants of this part of the shore include:

- shrimps, including the snapping shrimps (*Alpheus* species); *A. richardsoni* is confined to the coast north of the Manukau Harbour in the west and Tauranga in the east, and is the main producer of that snapping sound one may hear at the beach, particularly on a falling tide

- the common swimming crab

- worms, as well as the acorn worm (*Balanoglossus australiensis*; actually not a worm at all, but related to the sponges and originally from eastern Australia)

- the ostrich foot snail (*Struthiolaria papulosa*)

- various echinoderms; these include starfish such as the comb star (*Astropecten polyacanthus* — an interesting animal; it contains the deadly neurotoxin tetrodotoxin and is predated on by *Charonia* trumpet shells) and the burrowing brittle star *Amphiura aster*, as well as sea urchins (also echinoderms) — on such beaches it is not usually the sea-egg with the nasty spikes one bumps into, but rather ones with just small slender spines buried in the sand, such as the heart urchin (*Echinocardium cordatum*). The snapper biscuit or sand dollar (*Fellaster zelandiae*) is the perfect echinoderm for skimming the water with

above **A boulder beach on andesitic Little Barrier Island, Auckland. Periwinkles are totally lacking, and barnacle sand limpets are disturbed by the constant motion on this beach, but the more wave-stable *Nerita melanotragus* is common, as are topshells (one, *Melagraphia aethiops*, carries a coating of coralline algae). Under boulders one can find gastropods such as *Cookia sulcata* (the more-exposed equivalent of *Lunella smaragdus*) and, at the sublittoral fringe, the large stable boulders are fringed by pink with large brown algae *Dictyota kunthii*, *Carpophyllum plumosum* and *Cystophora retroflexa*. A red algal turf continues below the browns.**

- a sea cucumber, *Taeniogyrus dendyi*, which burrows in lower shore.

BOULDER BEACHES

At the other extreme from a muddy beach are the boulder beaches, with a median grain size of 1024 mm; in order of increasing size, smaller-grained gravel beaches are known as granule, pebble and cobble beaches (the Wentworth Grain Size Scale). All share certain characteristics; particularly on a high-energy shore, they become wave-sorted with the larger stones at the bottom and the smaller

above **A gravel beach, with some sand, formed from greywacke. Opotiki District.**

particles at the top, according to gravity. Only hard rocks are capable of being ground into boulders, such as greywacke, basalt and andesite. The organisms present vary greatly depending on the stability of the boulders — very few can withstand perpetual crushing on wave-exposed, fine-gravel beaches, but in those composed of more-stable, larger boulders life is much easier. Crabs in particular are particularly suited to this type of environment.

The higher parts of northern boulder shores are often visited by the shore skink (*Oligosoma smithii*) and the egg-laying skink (*O. suteri*), eating isopods; shrimps and snail might feed further down and, below mean high water neap (MHWN), decaying brown algae may fill the spaces between boulders.

PEBBLE OR GRAVEL BEACHES

Intermediate between sandy and boulder beaches are those made of pebbles (2–64 mm in diameter); these are found on many of our offshore islands and other moderately exposed coasts with a more inclined slope than that of sandy beaches, such that the force of water is enough to wash away the smaller sediments. Beaches made of deep gravel, moving about with each new wave, are very hostile to any life forms and hence there is less to write about them from a biota point of view!

NO PLACE FOR PEOPLE: THE MUDDY WETLANDS OF SHELTERED SHORES

MUDFLATS

Mudflats are, as opposed to sandy beaches, wide, flat, boggy and often smelly places, disagreeable to many of us. Particularly characteristic of the large, shallow and

above **Mudflats exposed at low tide and surrounded by a saline wetland. Kawhia Harbour, Otorohanga District.**

enclosed west coast harbours such as Manukau, Raglan and Kawhia, they are present in suitably sheltered reaches of all our estuaries and harbours. Being extremely sheltered, there is minimal wave action and this allows even very fine particles suspended in the water to settle down to the bottom, creating mudflats of fine silt rather than beaches made of coarser sand. The mud of our estuaries tends to be silt rather than clay (diameter less than 0.004 mm), unlike in Australia, and common minerals in mud and mudstone include quartz, feldspar and mica as well as clay minerals.

The swash and backwash are both about equal as well as being very mild; hence, there is an even distribution of particle sizes across the mudflat rather than coarse ones at the top and finer ones lower down. Mostly very fine clay and silt particles, the spaces between the particles are equally small, which causes poor oxygenation except where animals have burrowed holes through the mud; animals must draw water down into their burrows for adequate oxygenation. There is usually also a lot of organic debris which bacteria have to digest anaerobically, producing hydrogen sulfide (and a smell). The hydrogen sulfide converts iron oxides to black iron sulfide, and therefore the black anaerobic layer, present in other beaches but usually at greater depth, comes up very close to the surface.

Freshwater run-off tends to define the shape of mudflats more than the sea, with channels and flats changing as run-off and rivers gradually change.

Zonation is still present here; lower down, there are crustaceans such as the

snapping shrimps (*Alpheus* species) and a mantis shrimp, *Heterosquilla tricarinata*, which often attacks the snapping shrimps. Further up, on the middle shore, we find *Macrophthalmus hirtipes*, the stalk-eyed mud crab (another crustacean) as well as bivalve molluscs, including the often very abundant cockle (*Austrovenus stutchburyi*) — a key food of oystercatchers and godwits and whose discarded shells collect in large shell banks, often a metre deep — the wedge shell *Macomona liliana*, which feeds off plankton-rich puddles left as the tide goes out and, slightly higher up, another bivalve mollusc, the nut shell, *Nucula hartvigiana*. Other bivalves live further down, such as *M.* and *Cyclomactra ovata*, and snails such as the whelk *Cominella glandiformis* (a predator of living cockles), cerith (*Zeacumantus lutulentus*) and top shell (*Zediloma subrostrata*) live in this zone also. Finally, typical of the upper shore are the mud snail (*Amphibola crenata*) and the tunnelling mud crab (*Austrohelice crassa*); the mud crab's zone extends up to the inner edge of the saltmarsh, which marks the high-tide level; it is only active when the tide is out, unlike *Amphibola*.

As we get to shallower and more-sheltered waters, such as estuarine mudflats, the plants that colonise the intertidal zone tend to be higher plants, mostly angiosperms, creeping into the sea from the land, rather than the algae of rocky shores creeping up from the subtidal zone. These plants create biomass and trap sediment so that over time there is a gradual build-up of material and, in due course, dry land is formed. One may again observe zonation from the communities of open sea all the way through to dry land where that process is going on, with the youngest land being formed at the seaward edge of it.

The first plant species to take hold is *Zostera muelleri* or eelgrass, a type of seagrass although not a relation of land grasses; it is our only plant that can tolerate submergence in seawater, although unfortunately it has been joined by the introduced *Spartina* species. Covering wide swaths of the shallows, it was once much more common in many of our harbours than it is now, thanks to the activities of man (mainly run-off from the land, causing increased sedimentation and loss of water clarity), although it still covers 50% of the bottom of the more pristine Parengarenga Harbour and can be found in abundance at Auckland's St Heliers and Okahu bays; it is important as a nursery. Seagrass is an angiosperm, a flowering plant, that has successfully adapted to the maritime environment, such that it can complete its whole lifecycle under water. Other plants certainly can survive with their lower portions immersed in water, but in New Zealand only *Zostera* can live completely under the waves. It occupies the zone from the mean tide level to just below extreme low water, where there are wide flats but sufficiently brisk water movement to prevent smothering and the saltiness is not too low, and harbours its own distinctive community of crustaceans, worm, bivalves, gastropods and others, including the limpet *Notoacmea scapha* which feeds on *Zostera*'s blades and the interesting *Haminoea zelandiae*, a bubble shell which feeds mainly on green seaweed *Ulva*, itself attached to pieces of shell.

MANGROVES

In the northern third of the North Island, as opposed to the rest of New Zealand, the next plant up in a sheltered estuary or harbour is usually a mangrove, *Avicenna marina* subsp. *australasica*. The southernmost species of mangrove in the world, it grows naturally as far south as Kawhia Harbour in the west and Ohiwa Harbour in the east, fairly similar to the biogeographical boundary that we have already met for many other northern species

left **Tall mangrove forest, near Kaeo, Far North District.**

such as kauri, puriri and taraire, although it has been introduced further south, e.g. at Tolaga Bay. It is relatively intolerant of the frosts which increasingly stunt its growth in its more southerly ranges. It occupies the boundary between the upper and middle shore zones. Although compared with mangrove forests from more tropical climates ours might be considered depauperate, it is a very important part of the ecosystem, being a leading natural reclaimer of the sea and one of the most productive types of community in terms of the amount of plant material produced in a given time. Silt and debris from the land are deposited around it, building up this new land; it is often full of nutrients but gummy in texture and very poorly aerated; fewer animals can tolerate this rather than open mudflats, although the tunnelling mud crab and the bristleworm *Nicon aestuariensis* do. Mangroves are also important nurseries for small fish, although less so here than in the tropics, and prefer brackish water (about 25–50% of normal sea-water salinity).

Mangroves produce seeds (propagules) that float with the tide and are virtually seedlings before they even drop off the parent tree, with two folded leaves protecting the shoot and hairs in a clump at the base that will become the roots. Three days after it lands, the leaves unfold and roots emerge to push it upright.

Mangroves have a number of specialisations that enable them to flourish in environments which are hostile to other plants. These include pneumatophores, to allow their roots to respire outside of the anaerobic, waterlogged mud in which they live, and a large radiating root system to resist the tide and anchor them in that viscous, sulfurous ooze.

Even within our region, it is easy to see the influence of the steadily decreasing temperatures as one goes further south; the mangroves of the far north, which can grow up to 9 m tall, would tower over those of Auckland; and those in Kawhia Harbour are just small shrubs, very few and far between. However, there is also a variation in the height of mangroves in the same location, as those nearest the channels of the sea grow larger than those stuck in the mudflats to landward, due to increased availability of nutrients.

Mangroves also have algae associated with them, including Neptune's necklace and small red algae. Oysters, tiny black mussels and barnacles (e.g. *Elminius modestus*, below the middle/upper shore zone boundary) may festoon their branches, with crabs, pipis, whelks, mud snails, turret shells, shrimps and cockles all living in the mangrove community. Many fish, including kahawai, parore, snapper, flounder, grey mullet and eels, visit at high tide, and smaller fish such as spotties and gobies find refuge within their maze. Some of the smaller fish, particularly gobies, also survive in water-filled burrows during low tide. However, one does not often observe many birds in their branches, as insects are not common.

Over time, mangroves will end up trapping so much sediment that land builds up, colonised initially by glassworts, rushes and sedges to eventually turn into saltmarsh and salt meadow; large mangroves may be found growing within salt meadow that is no longer covered by the tides.

SALTMARSH

Saltmarsh vegetation occurs roughly between the highest level of the neap high tide and the highest level of the spring high tide, and in northern New Zealand may often be found just above the mangroves. It is therefore only irregularly inundated, and the soil becomes hypersaline as the water component of saltwater is evaporated off the surface during the long dry intervals, leaving its salt behind in the soil. Different species find different ways of coping with this hypersalinity; they may be salt excretors (like mangroves), salt avoiders that try to limit their intake of salt, or salt accumulators, the most common example of which is *Sarcocornia quinqueflora* or glasswort, which also lives the closest to the sea. This is a succulent whose characteristic

below **Glasswort saltmarsh, near Miranda; small mangroves are also present in this image, as is the sea rush *Juncus kraussii*. Note that the lowest levels are devoid of terrestrial plants; just dry mud is found in that location. In the background is some silver tussock, at the landward edge of the sea meadow. Waikato District.**

thick, soft structures accumulate water. It is less common in the north than it is further south, however, where it can form wide, lush zones. In brackish channels nearby we might also find rushes (*Apodasmia* and *Juncus*) and sedges (*Carex*). The sea rush (*Juncus kraussii)*, the jointed rush (*J. articulatus*), oioi and the tawny jointed rush/oioi can all cope with salty soils. Landward of glasswort, in areas where the saltmarsh is rarely covered except by the highest tides, soil drainage improves and salinity declines to the point where we find ourselves now in salt meadow, dominated by the sedges and rushes but also now with small trees such as saltmarsh ribbonwood (*Plagianthus divaricatus*) and carpets of *Selliera radicans* and bachelor's buttons (*Cotula coronopifolia*). Flax (*Phormium tenax*) and raupo (*Typha orientalis*) may be found, especially where freshwater enters the area. Finally, we end up in a zone of coastal scrub such as manuka and cabbage trees. Pohutukawa, ngaio and taupata (*Coprosma repens*) are also adapted to a coastal, salty environment; as with flax, they withstand glare and water loss by means of hard cuticles and hairs on the undersurface.

As one goes progressively higher, terrestrial animals also take over from marine ones — burrowing earthworms from burrowing marine worms, as well as insects, spiders, beetles and land birds.

Over time, assuming that sea levels remain stable, there is a trend for mudflat to turn into saltmarsh, salt meadow and then dry land because the plant roots help bind the mud particles together, the still water that they create around them encourages sediment to settle and, when they lose their leaves or die, their debris adds to the humus layer and becomes soil.

A SHELTERED SHORE OF INTERNATIONAL IMPORTANCE: THE FIRTH OF THAMES

The Firth of Thames is a huge salty wetland of international importance, recognised by being designated a Ramsar site. It is composed of shallow estuary, mangroves, saltmarsh, swamp, shell banks and grass flats. The cockle shellbanks form a 'chenier plain', graded by the tides and storms; it is slowly

left **The nationally significant Nukuhou Saltmarsh at Ohiwa Harbour, Whakatane District.**

top **Seabirds flock over saltmarsh bordering the Firth of Thames (glasswort, mangroves, rushes and sedges). Miranda, Waikato District.**

bottom **Mangroves growing on the edge of a chenier ridge. Miranda, Waikato District.**

being colonised by plants but the sea fights back in stormy weather, clearing away the vegetation. The rivers feeding into the firth bring sediment rich in humus and nutrients; drainage off the Hauraki Plains, application of fertiliser and the disintegration of the peat and mineral soil which is now brought down the rivers has encouraged the formation of the vast mangrove forests which in the 1940s were only scant. With these nutrients, the shallow, easily warmed and slightly fresh (due to the rivers) waters are ideal for mangroves. The sediment builds up around the mangroves, and slowly the process of reclamation into dry land is begun.

Vast flocks of birds can often be observed feeding in the saltmarsh at low tide around Miranda (there is a bird hide set up for this purpose). Not only is the Firth of Thames exceedingly productive, but the birds can also fly over to west coast harbours such as the Manukau when the tide comes in at Miranda and continue feeding there as the tide on the west coast will be going out, a rare but fortuitous happenstance.

Shell banks are also found in other parts of the north, including upper reaches of the Waitemata Harbour, such as at Shoal Bay on the North Shore and around Pollen Island near the Northwestern Motorway.

ROCKY SHORES

Rocky shores have a greater variety of life than do sandy beaches. On the rocky coast there is a lack of soft sediments and soil, just as on the top of a mountain, so life has to live directly on the exposed bedrock. However, compared to a sandy shore, at least here animals and plants can find a firm foothold without being washed clean with each wave and tide, and animals can find sheltered crevices and rock pools to hide in and protect themselves from the vagaries of the coast's environment. Many species are also intolerant of being covered in sediment, which is obviously less on a rocky coast than a sandy one. However, with more life forms there is also more competition.

As with beaches, there are numerous bands or zones, one below each other, where different organisms predominate. In sheltered areas, zonation is confined fairly much to the intertidal zone. However, as we go to more exposed locations, with large waves, swell and spray that may reach high above the high-tide mark, these zones stretch further upwards to the very highest level that the salt spray reaches at its most ferocious high-tide maximum. In the most exposed shores it is hard to speak of an intertidal zone at all, given the size of the waves and their associated spray.

Higher up the shore, the amount of drying is more extreme and rocky shores heated by

above **Rocky shores composed of hard greywacke in the eastern Bay of Plenty, Opotiki District.**

the sun can become much hotter when the tide is out than when the cool water returns. This, the harshest environment, can only be tolerated by a few creatures. As we go further down into the eulittoral, the amount of drying out and temperature fluctuation becomes less extreme and more life can flourish there as a result; however, with more organisms there is more competition and those that flourish further up may not be able to get a toehold lower down.

The three basic zones of a rocky shore are:

- the upper shore, above mean high tide, characterised by periwinkles, lichen and blue-green algae (also called the supralittoral). This zone often appears black

- the middle shore (eulittoral), characterised by acorn barnacles (e.g. *Chamaesipho columna*) but also home to other creatures such as oysters (*Osteridae*), between mean high tide and mean low tide; it is often white in colour

- the lower shore, which never completely dries out, below mean low tide or in permanently wet rock pools, dominated by algae. It is often heralded by a continuous pink zone of coralline algae and followed by a brown zone of large ochrophytan algae — our seaweeds, e.g. *Carpophyllum* species.

The young of the sessile organisms (such as barnacles) are free-swimming and much more prone to desiccation; it is only when they mature that they settle down on the shore and adopt their various strategies to tolerate the severe conditions.

On exposed shores the large waves wet an area much higher up than that strictly between the tides, allowing organisms that prefer to stay wet to live higher up. Different conditions also influence which organisms dominate: north-facing rocks dry out more;

top **Zonation on a rocky shore, Motuora Island, Auckland. Algae are visible (mainly coralline with some brown algae in the deeper, shaded part) in the left foreground. Above this to the right is a zone dominated by barnacles. Above this again, on the slope occupying the right-hand side of the picture, is a very bare zone, with a few periwinkles dotting the surface and some lichens also present.**

bottom **A shore platform exposed at low tide. Wainui Beach, Gisborne District.**

water laden with sand and sediment smothers many organisms but others, such as the bristleworm *Neosabellaria kaiparaensis*, need sand to build their tubes. Freshwater run-off dilutes the seawater; some shore inhabitants,

top **The supralittoral zone on a rocky shore, Peach Cove, Whangarei District. Note the terrestrial plants, including a straggly pohutukawa, on the top. This changes into an orange- and cream-coloured lichen zone further down, the terrestrial plants surviving better on the less-exposed left-hand side of this rock. Below the lichens is the start of the intertidal zone.**

bottom **Barnacles in the upper eulittoral. Whatipu, west Auckland.**

such as acorn barnacles, can tolerate such dilution while many others cannot.

The type of rock (hard or soft), the amount of exposure and the amount of sediment determines the topography and the biological communities that form on that rocky shore. Generally, the most exposed shores are made of harder, more-erosion-resistant rocks, except in Gisborne District where the hard greywacke and volcanic rocks are not present and the softer sedimentary rocks of that region erode more easily, forming large cliffs. Exposed shores also tend to have the clearest water, whereas the sheltered shores further up in harbours are washed by waters thick in sediments. This combination of softer, more crumbly rock, which offers less purchase to organisms such as algae, mussels and barnacles, and sediment, which 'clogs up' and buries coastal communities, results in sheltered shores having a relatively

depauperate flora and fauna in comparison with harder, more exposed shores. There is often a shore platform around the intertidal area, where waves and sediment scouring have 'levelled off' a plain since the sea has risen to its present level after the end of the last glacial period; again, the softer rocks such as the Waitemata Sandstones and those in the Gisborne District have left a much larger platform than hard greywackes. At the seaward edge of this plain there is often also a drop-off of a metre or so. The more sheltered shores are often cut off at the bottom ('abbreviated') by the sandy or muddy bottom of the harbour on which they are located.

Other factors that influence the biology of the rocky coast include water temperature and salinity. For instance, marine macroalgae (i.e. seaweeds) are typically more diverse in cooler waters and higher latitudes, i.e. on our cooler west coast and the more southern parts of New Zealand. In fact, algae change depending on the season. Salinity may vary also, increasing with evaporation (for instance, in rock pools) and decreasing with freshwater runoff.

In the supralittoral or splash zone, coastal forest including our emblematic pohutukawa and other species such as taupata of the 'adlitorral' give way to the hardier but still terrestrial lichens and finally the marine algae, more common on harder rock than softer. The uppermost lichens are the yellow or orange *Xanthoria* and *Caloplaca*; then come the black *Verrucaria* and further down, to among the periwinkles, is the toughest of the terrestrial organisms, the black *Lichina pygmaea*. Periwinkles (the banded periwinkle *Austrolittorina antipodum* and others, depending on the degree of exposure) — snails (gastropod molluscs) that live at the littoral fringe, just above MHWN — are similarly the marine molluscs that are most resistant to desiccation (marine because their young are swimmers and they have a tiny gill). Cyanobacteria can also often be identified, when wet, as a dark green slippery area which becomes pale with salt when dry.

At the top of the eulittoral (the upper eulitoral) we start to find the acorn barnacle with, lower down, the larger barnacle *Epopella plicata*. On more-exposed shores, *Chamaesipho brunnea* starts to replace the acorn barnacle, although *Dicataeis orbita* prefers to dine on *C. brunnea*, which works to the other's advantage — another example of how varying conditions and biological controls can make different species more or less common. At this middle eulittoral level, on more exposed shores, we also find bivalves. First comes the very small black or flea mussel *Limnoperna pulex,* which may also find a place higher up among the barnacles (it comes into its own, in place of barnacles, in rocks surrounded by sand, where there is too much sediment for both barnacles and the predatory whelks). Then, in sheltered parts of Auckland and the Northland Region, with a few scattered colonies as far south as New Plymouth and the eastern Bay of Plenty, there is the historic habitat of the rock oyster (*Saccostrea cucullata glomerata*); it has been replaced to a large extent by the Pacific oyster (*Crassostrea gigas*, introduced from Japan in the 1970s), which prefers more-brackish waters in upper reaches of mangrove estuaries and is the basis of the oyster-farming industry. Another farmed mollusc is the green-lip mussel (*Perna canalicula*) of the lower shore and subtidal, more common here than further south; such farms may be plagued by the intertidal blue mussel (*Mytilus galloprovincialis planulatus*); in the natural environment, our fourth mussel, the ribbed mussel (*Aulacomya maoriana*), lives between the other two in the lower shore, and is particularly good at hiding among bull kelp on exposed shores.

Mussels in general are found on exposed

left **Hermit crab (*Pagurus novizealandiae*) feeding, Matheson's Bay Auckland. Photograph: Simon Francicevic.**

right ***Carpophyllum* species swirls in the sublittoral fringe at lower tide, with Neptune's necklace occupying slightly higher ground on the rock in the middle distance. Oysters dominate the middle eulittoral above the algae on this moderately sheltered shore. Browns Island, Auckland.**

shores such as those of our west coast, rather than the quieter bays such as those of eastern Northland. On more-sheltered rocky shores, just below the oyster line and just above the algal turf, we can often find a zone of serpulid tubeworms (polychaete worms that live in tubes that they can block off with an 'operculum') such as *Spirobranchus cariniferus*, as well as the barnacle *Austrominius modestus*. *S. cariniferus* lives in a little tube of its own building, filter-feeding in the currents when submerged.

Crabs of the rocky shores include the purple rock crab (*Leptograpsus variegatus*), living high on the shore and even roving into the bush in pursuit of snails on the Poor Knights Islands; the red rock crab (*Plagusia chabrus*), which rarely ventures out of water, living among seaweed in the tidal pools; and many others which occupy environments between these two extremes, such as the porcelain crab *Petrolisthes elongatus*, often found under rocks at mid tide, a filter-feeder.

The most common snails (technically, gastropods — molluscs with a muscular foot) are the black snail (*Nerita melanotragus*), on the littoral fringe and upper eulittoral among the barnacles and preferring harder shore, as well as *Diloma aethiops*, which grazes the periwinkle, barnacle and oyster zones. On the coralline turf (see below) we find the cat's-eye *Lunella smaragdus* (previously *Turbo smaragdus*) and the long-spired *Zeacumantus subcarinatus*. Other herbivorous molluscs such as limpets (*Cellana* species) and chitons also graze the intertidal zone, as do predators such as the thaids (e.g. *Dicathais orbita*, eater of mussels) and other members of the *Murex* genus, as well as whelks (some of which, like the harbour whelks *Cominella glandiformis* are actually scavengers of dying or dead bivalves, rather than predators). True predators exist also, such as the oyster borer (*Haustrum scobina*) — a whelk with a taste for oysters — sea slugs which eat hydroid polyps, and trumpet shells, which attack sea urchins.

Algae are a simple form of plant, without the complicated structure of wood, xylem, phloem, leaves, roots and other specialised organisms that higher plants such as gymnosperms and angiosperms have; they

are divided into three groups depending on the pigments they express — the red, green and brown algae, although they don't always look the colour they should! The highest alga is usually the red alga *Capreolia implexa*, which in shade can grow to the top of the barnacle zone. In the lower eulittoral, on reef platforms, we then find a level 'coralline turf' (a red alga) that goes down to the average low water; it starts off with a pink veneer (the 'pink line'), then sends out jointed branches; on highly exposed shores we may see only the crustose forms. The most common coralline alga in the north is *Corallina officinalis*, which coats our rock pools like a spongy carpet, up to 4 cm high; another *Corallina* is *C. armata*. The genus *Corallina* is a member of the Corallinoideae subfamily of the Corallinaceae; Corallinoideae are a type of erect red algae made up of jointed segments impregnated with calcium carbonate (lime), separated by uncalcified joints (genicula), the other Corollinaceae being non-articulated. Even though *C. offinalis* is the most common, all these algae do contribute to the coralline turf; some are much larger and others are epiphytic on *C. officinalis*. When they die, they break into calcerous fragments that then become beach sand. They form a turf which supports an entire miniature ecosystem with crabs, molluscs, other crustaceans, worms and a caddisfly larva. Sponges and brown algae may also be found from around this level down; especially evident is Neptune's necklace, *Hormosira banksii*, as well as the brighter green alga, extending from the turf downwards. The water-filled beads of this seaweed allow it to store water, which enables it to live relatively high up the littoral fringe.

At the bottom of the shore is the brown line, marking the sublittoral fringe (around the low water level) where large brown algae with branches off one main stem, often with hard oval floats, take over from the coralline turf. These plants are only occasionally exposed to the air, at low tide in calm conditions. *Carpophyllum* species are particularly common in the Aupourian Province and include *C. maschalocarpum*, often present in tidal gullies and rocky guts,

left **A rock pool lined with coralline algae and scattered Neptune's necklace; above the pool are barnacles and oysters, more tolerant of desiccation. Motuora Island, Auckland.**

keeping moist with each storm surge; and *C. angustifolium*, common on exposed vertical rock faces of our eastern coast, the habitat that on the west coast and south of East Cape is occupied by the bull kelp *Durvillaea antarctica*. Two other *Carpophyllum* species are subtidal, reaching up from the bottom of rock pools and the sea floor to the brightly lit surface. Red algae are also present. The common kelp (order Laminariales) of the Hauraki Gulf is the large-stalked *Ecklonia radiata,* which can survive further and further down into the sea as one heads out of the inner Hauraki Gulf to the Poor Knights Islands with its increasingly clear waters. However, in the most exposed eastern locations (e.g. the Poor Knights) we may again encounter *D. antarctica* (a fucoid rather than a laminarian) despite it being, as mentioned, more common on the cooler and more exposed west coast.

HARBOURSIDE SHELTERED ROCKY SHORES

As one goes to very sheltered shores, such as in our harbours, pohutukawa now hang right over the shore, compressing the zones of the supralittoral. Lichens are not present

on more crumbly rocks and the barnacle *Austrominius modestus* replaces *Chamaesipho columna* at the top of the eulittoral. Shell-boring polychaete worms, such as *Boccardia* species, may decrease the commercial value of cultivated shellfish by their activities. In general, harbours have fewer species, perhaps because of the amount of sediment in the water or because of the variable salinity. Oysters (*C. glomerata* and *C. gigas*) are still common, even when it is too muddy for *Limnoperna* mussels. *Spirobranchus cariniferus* was more common but has often been displaced by the Pacific oyster *C. gigas*. Brown algae are disadvantaged by this, as are the red algae. Sponges become more dominant as the brown algae fail. The coralline turf becomes increasingly replaced by Neptune's necklace with increasing shade, increasing silt and decreasing salinity; in very silty water this species also fails. At extreme low water spring (ELWS) we find the flat, cool-temperate oyster *Ostrea chilensis* and the sea squirt *Microcosmus squamiger*. However, in the sheltered, more-sediment-laden inner shores, the clouded water also allows the kelp *Ecklonia radiata* to come into the intertidal region.

The periwinkles penetrate into clean water in the harbour, and *Nerita melanotragus* snails penetrate into the eastern Northland harbours but not very much into those of Auckland. The largest predators in the harbours are the trumpet shells, around low water. The cat's eye snail grows to its largest size in the harbours and among mangroves.

In the Waitemata Harbour in particular, because of the amount of overseas traffic, there live a large number of introduced species, such as the bryozoan *Watersipora*

left **Zonation in a harbourside rocky shore: Snapper Bay at low tide, Motuihe Island, Auckland. Note that the upper eulittoral is dominated here mainly by oysters; lower down are coralline and brown algae, with large *Ecklonia radiata* just breaking the water's surface on the right.**

above **The sheltered backwaters of Tauranga Harbour. Pine plantations dominate Matakana Island in the foreground, with a fringe of saltmarsh and mangroves in the intertidal zone. Western Bay of Plenty District.**

right **An enriched algal shore at low tide in January, Rangiwhakaea Bay, Great Barrier Island, Auckland. Note the isolated, small green and red algae in the mid eulittoral. Large brown algae obscure the pink line at the sublittoral fringe.**

arcuata and the green alga *Codium fragile* subsp. *fragile* from Japan, closely related to the native *C. fragile*, around the low eulittoral, wharves and buoys. Native molluscs have been replaced by new immigrants. As mentioned, Pacific oysters have expanded all around our coast and even to the South Island, and are an important farmed oyster. When tides are excluded, such as in Orakei Basin, Neptune's necklace is replaced by green algae, which when it rots can smell repugnant.

ENRICHED ALGAL SHORES

The richest algal shores are found further out than the harbours and Hauraki Gulf, on the more exposed coasts to east and west, although with some protection from maximal exposure. These moving waters are free of silt and the clear water allows good illumination. The algae classically are green at the top, then brown, then red, although some simple reds may grow at the very top. At the mid eulittoral are also the green algae such as the sea lettuces (*Ulva* species). Below the mid eulittoral, in clearer water *Corallina* is supplanted by two red algae that typify enriched algal shores in the Aupouri Province, *Gigartina alveata* and *Pachymenia lusoria*, below which one may still find a coralline turf but one more commonly dominated on such shores by *Jania*

left **A very obvious pink line, Tiritiri Matangi Island, Auckland, at low tide and ebb swell, where it never dries.**

opposite **Under a boulder at Rangiwhakaea Bay, Great Barrier Island, Auckland. Organisms not seen on the sunny side of the rock, such as a cushion star and sponges, are easily spotted when it is turned over.**

species than by *Corallina* species, followed by lower tidal *Gigartina* species. At the bottom of the eulittoral, *Carpophyllum* species in particular may be common, forming a dense curatin that shades a dark purple world of red algae, but brown algae of sheltered shores such as *Hormosira banksii* are less common. In the winter eulittoral one may find plants, including juvenile *D. antarctica* (on the west coast) and *Porphyra columbina*, which may not survive the summer. *Petalonia fascia* and *Scytosiphon lomentaria*, both of which are small brown algae, may also appear in the winter eulittoral but not in warmer seasons. Hence there can also be a significant change in the shore appearance as the seasons change.

In the shade live different organisms, as this offers protection from extremes of temperature and wave action as well as from drying from the sun; the alga *Apophlaea sinclairii* likes the shaded hard rock boulders of the Coromandel (and elsewhere) and different lichens are also suited to different aspects of a rock, whether shaded or not; this is called 'aspectation'.

UNDER-BOULDER COMMUNITIES

Often the best place to find life at the seaside is under stable boulders on moderately exposed shores. On these undersurfaces, where there is no light for plants, filter-feeders such as sponges (*Porifera*), bryozoans, tubeworms, ascidians (sea squirts — our aforementioned distant vertebrate relatives) and filter-feeding gastropods such as some limpets predominate.

On mainly sheltered shores, under-boulder communities become evident from the middle eulittoral with sessile barnacles, tubeworms and anemones dominating at that level, bryozoans and tubeworms in the lower eulittoral (at the level of the coralline turf), and sponges under the boulders of the sublittoral fringe. Bryozoans, although present on almost all sponge boulders,

are more common under stable stones of higher-energy shores (i.e. stones that do not get turned over). In very close shelter, muddy sand accumulates around boulders; underneath boulders, resting in the black, anaerobic mudflats of ultimate shelter live only a very few species (e.g. polychaete worms, their feeding tentacles directed outwards into the surrounding sediment).

These animals are in turn preyed upon by slow-moving carnivores. Predator species may include starfish (e.g. the cushion star *Patiriella regularis*), gastropods such as the nudibranch slugs and the rockfish *Acanthoclinus quadridactylus*. Crabs are also common predators under boulders and retreating into crevices; other larger, swifter crabs also live on the more exposed shores and amongst the algae. Several forms of chitons have also moved to a diet of sponges.

ROCK POOLS

Rock pools are a favourite of children. The higher and shallower the pool, the more extreme the environmental fluctuations and the more difficult the environment; in sunlight, temperature and saltiness increase (due to evaporation), as does oxygenation, due to photosynthesis, which in turn causes the pH to become more alkaline. Rain will depress the salinity and at night the pH and oxygenation drop. Animals and plants in pools are often well above their usual open rock zone limits; *Corallina* species and Neptune's necklace may be found in the upper eulittoral; brown algae of the sublittoral fringe, such as *Carpophyllum* species, may be found in the lower eulittoral amongst the *Corallina* and Neptune's necklace. *Corallina* species may support molluscs such as young cat's eye and snails, as well as a spire shell, *Zebittium exile*. The crustacean isopods, decapods and amphipods also hide in among

above **The soft cliffs of Tolaga Bay, Gisborne District.**
left **Rock pool. Motuora Island, Auckland.**

the coralline turf. Worms live near the base of the coralline turf and the marine caddisfly *Philanisus plebeius* (one of the very few marine insects anywhere in the world) may be found in the pools, along with small fish, the most common of which are the triplefins (Tripterygiidae) and the blenny *Parablennius laticlavius* (erroneously lumped together as the 'cockabullies' in common parlance). The diversity and size of the triplefins peaks in the New Zealand region, making them as iconic in their own way as kiwi are on land.

In Gisborne District, at Tolaga Bay, the soft cliffs prove impossible for barnacles; instead there is an algal film at the cliff base in which live limpets such as *Cellana flava*, common on all siltstone and muddy limestone shores. Also south of East Cape, at low tide, lives the ascidian *Pyura spinosissima*.

Crevices within the rocks may harbour polychaete worms and bivalve molluscs, and provide a refuge for air-breathing spiders and other arthropods feeding on decaying fragments of matter.

Limpets, bivalves, crustaceans and polychaete worms may all burrow into soft rock, causing bio-erosion.

VERTEBRATES OF THE SHORE

The main vertebrates to be found on the shore are, like anywhere else in New Zealand, the birds and, under the water, fish, although undersea life is beyond the scope of this text.

FISH

Small fish survive in rock pools, often above even high tide, as mentioned above. Perhaps one may consider that, with this exception, saltwater fish should be excluded from this text since they are fully marine. Nevertheless, fish do influence life above the sublittoral since, when the tide comes in, so do the fish — such as gobies, blennies and the wrasse (*Notolabrus* species). This last is a significant predator of barnacles at higher tides.

REPTILES

Some lizards venture down to the coast; several *Oligosoma* species can be considered shore specialists, with the egg-laying skink and Fiordland skink (*Oligosoma acrinasum*) living in rocky cracks within the splash zone (see Chapter 7).

New Zealand is one of the few landmasses in the world where snakes are not present and Customs staff remain vigilant against their importation. Turtles are usually also considered creatures more of the tropics. Nevertheless, on our northern shores seasnakes and turtles do occasionally make landfall.

BIRDS

WADING BIRDS

The large amount of life present in mudflats in particular, but also on other coasts, is a particular attraction for wading birds which flock to feed on these organisms at low tide (at high tide, fish do the same). As such, they may often appear to compete for the same food — but each has a different feeding technique. In particular, their bills are different; some have bills that are longer than others, which means that they are probing for food at different depths. Wading birds include the pied stilt (*Himantopus himantopus*), which breeds in wetlands in spring and summer; the eastern bar-tailed godwit (*Limosa lapponica*), which overwinters here (from Siberia and Alaska) from October to March; oystercatchers (*Haematopus* species), feeding mainly on cockles and mussels, splitting them open with their strong beaks; the banded dotterel (*Charadrius bicinctus*), which nests in hollows in sand and shingle as well as along river flats; the lesser knot (*Calidrus canutus*), also from eastern Siberia but with a shorter bill (35 mm vs 80 mm) than the godwit, so they feed at different depths and are often seen together); and another Siberian, the curlew sandpiper (*Calidris ferruginea*). The wrybill (*Anarhynchus frontalis*), an endemic which breeds in the braided rivers of Canterbury and Otago, migrates in late summer up to our estuaries and harbours to overwinter (especially the harbours of Auckland and the Firth of Thames); it is the only bird which has a beak that curves laterally to the right, and its population has been slowly declining.

Migratory birds such as godwits face dangers on their pathway — many stop in the Gulf of Bo Hai, a vital feeding ground on their way back and forth, but development in China and South Korea is diminishing this resource and endangering their future existence.

above **New Zealand dotterel. Mimiwhangata, Whangarei District. Photograph: Simon Franicevic.**

The endangered shore plover (*Thinornis novaeseelandiae*) was returned to Motutapu Island in the summer of 2011/12.

As well as seabirds, many of the birds described in Chapter 8 also visit the coast, and birds such as ducks, crakes, black swans (*Cygnus atratus*), introduced geese, herons and egrets are a not uncommon sight in quieter saltwater and their surrounds; the vulnerable New Zealand dabchick (*Poliocephalus rufopectus*) also frequents the Matata Lagoon in the Bay of Plenty. The white-faced heron (*Egretta novaehollandiae*) is as often observed in coastal locations as by freshwater, and the reef heron (*E. sacra*) is most common by the coast and in coastal wetlands in Auckland and Northland. Perhaps the best-known egret is the kotuku or white heron (*E. alba*); this bird which, along with the little egret (*E. garzetta*), can be very rarely seen in coastal wetlands, has its only breeding site in New Zealand in the Okarito Lagoon of South Westland.

SEABIRDS

The birds described above all utilise the coast for food. However, seabirds — i.e. birds that spend most of their active life at sea, only coming ashore to rest and breed — also nest in our area. New Zealand has approximately a third of worldwide seabird species, and more native and endemic seabird species than native land, coastal and freshwater bird species!

The largest seabirds, the albatrosses (both the great albatrosses and the mollymawks), are rarely seen and do not breed in the north. However, several petrels do, mainly on offshore islands which are usually difficult to access unless one has a boat, and people are often forbidden to land in any event. It is likely that before the coming of man and his flock of new predators, most of these seabirds were much more common on the mainland coast and even inland. For instance, Parkinson's petrel (*Procellaria parkinsoni*) used to breed on the mainland North Island and also near Nelson in the South Island, but now only breeds on Little Barrier and Great Barrier islands. Perhaps the easiest to see is the grey-faced petrel (*Pterodroma macroptera gouldi*), which nests on islands and some mainland cliffs from Taranaki's Cape Egmont around to Gisborne, including the Three Kings Islands and also, for those wanting to view them, the open sanctuary of Tiritiri Matangi Island. They are also abundant in the Aldermen, Mercury and Three Kings islands.

Other petrels that nest in the north include the following:

- flesh-footed shearwater (*Puffinus carneipes*), breeding on the Hen and Chickens and Mercury islands
- Buller's shearwater (*Puffinus bulleri*), which breeds only on the Poor Knights Islands, although the burrows there can be very dense; the entire worldwide population of Buller's shearwater, Parkinson's petrel and Pycroft's petrel only breeds in the Hauraki Gulf

top **The recently rediscovered New Zealand storm petrel. Hauraki Gulf, Auckland. Photograph: Brent Stephenson.**

bottom **The gannet colony at Muriwai, Auckland, became so large that as well as breeding on the safer offshore stack it spilled over to the mainland in 1979 (foreground).**

- Parkinson's or black petrel (*Procellaria parkinsoni*), often seen around the coast but breeding only on Little and Great Barrier islands; it can disperse at sea as far away as Australia and Ecuador

- Cook's petrel (*Pterodroma cookii*), which has a large colony (its main breeding area) on Little Barrier and also breeds on Great Barrier

- the very similar Pycroft's petrel (*Pterodroma pycrofti*), which breeds only on the Poor Knights, Hen and Chickens and Red Mercury islands

- black-winged petrel (*Pterodroma nigripennis*) of the Three Kings Islands, Motuopao, Matapia and Simmonds islands around the Aupouri Peninsula, Motu Kokako (the hole-in-the-rock island), Mokohinau, Portland and East islands; they seem to be expanding their range and are also found in the Kermadec and Chatham island groups

- fluttering shearwater (*Puffinus gavia*), which breeds from the Three Kings Islands down as far south as Marlborough

- little shearwater (*Puffinus assimilis haurakienis*), of the Hen and Chickens, Mokohinau, Mercury and Aldermen islands

- common diving petrel (*Pelecanoides urinatrix urinatrix*), breeding again on small islands off the mainland North Island; vast numbers are present on the Mercury Islands and there is a colony on the Mokohinau Islands also

- white-faced storm petrel (*Pelagodroma marina maoriana*) on islands off the coast; there is a large colony on Flat Island in the Aldermen Islands and others are on islands such as the Mercury and Three Kings

- New Zealand storm petrel (*Fregetta maoriana*), thought extinct till 2003 but since rediscovered in the Hauraki Gulf; in 2013, a breeding site was discovered on Little Barrier Island and there may be others.

Petrels and shearwaters are also common on Cuvier Island.

Other seabirds include the following:

- blue penguin (*Eudyptula minor*), which is the only penguin that breeds in northern New

Zealand and can be found especially in the Bay of Islands and Hauraki Gulf

- Australasian gannet (*Morus serrator*), which nests in Muriwai, west Auckland, from July to February

- black shag (*Phalacrocorax carbo*), which breeds in many coastal locations such as sheltered harbours, in trees and beside rivers

- pied shag (*P. varius*), common from Raglan to Hawke's Bay and breeding in trees along cliffs

- little black shag (*P. sulcirostris*) and little shag (*P. melanoleucos*), of the coast and inland waterways

- spotted shags (*P. punctatus*) have a colony on Tarahiki Island (Shag Island) east of Waiheke Island, although they are more common further south in New Zealand, for instance, around Kaikoura

- gulls — the southern black-backed (*Larus dominicanus*), which can be seen both by the coast and inland; the red-billed (*L. novaehollandiae*), especially around Lake Rotorua as well as the coast and urban areas (there is a large colony on the Mokohinau Islands); and the black-billed (*L. bulleri*), which only has isolated colonies on some sand-spits in the North Island, being more common in the South Island. (When the Arctic skuas (*Stercorarius parasiticus*) come to the Southern Hemisphere for our summer, they can sometimes be seen chasing gulls and terns.)

- terns — the Caspian tern (*Sterna caspia*) breeds around the coast and in estuaries, and the white-fronted tern (*S. striata*) breeds on beaches and rocks. The black-fronted tern (*S. albostriata*) breeds in the inland South Island, coming north in autumn and winter. The fairy tern (*S. nereis*) breeds on the Northland east coast, overwintering in the Kaipara, Firth of Thames and Bay of Plenty; the New Zealand subspecies (*S. nereis davisae*) is critically endangered with fewer than 100 birds remaining. The grey tern (*Procelsterna cerulea*) usually breeds on the Kermadecs but has also bred on islands off our north and east coast, and the noisy little tern (*Sterna albifrons*) is common on harbours, coastal lakes and estuaries.

top **A flock of pied stilts in the mangroves. Miranda, Waikato District.**

bottom **Pied shags roost in a pohutukawa tree. Peach Cove, Whangarei District.**

MARINE MAMMALS

Venture to the coast near Dunedin and you are almost sure to find a marine mammal, most likely a New Zealand fur seal, hauled up sunbathing. Yet Dunedin children of the 1950s recall not ever seeing a single one; marine mammals had been hunted almost to extinction by man, holding on in places such as Fiordland and the subantarctic islands, from whence many (but not all — for instance, Hooker's sea lions, *Phocarctos hookeri*) have made a comeback. Northern New Zealand is further away from these areas of refuge and hence the comeback of these species is progressing more slowly; nevertheless, it would seem to be under way and one can certainly occasionally spot New Zealand fur seals (*Arctocephalus forsteri*) in particular in the water or hauled up on rocks around both east and west coasts and as far north as the Three Kings Islands.

Sometimes also seen from the coast are dolphins, orca, humpback and southern right whales (of the order *Cetacea*).

below **A New Zealand fur seal (*Arctocephalus forsteri*), lying on the rocky shoreline between Milford and Takapuna beaches, Auckland.**

THE FUTURE

It is likely that we shall see changes to our coastline in the future; a rise in sea level of between 0.18 and 0.59 m in the decade 2090–2099 compared with 1980–1999 was forecast by the Intergovernmental Panel on Climate Change (IPCC) in 2007. This excludes 'future rapid dynamical changes in ice flow', i.e. increased ice flow out of the Greenland and Antarctic ice sheets relative to what happened between 1993 and 2003, which is not unlikely. If it happens there will be a greater sea-level rise than the IPCC predicts. A temperature rise over the same period of between 1.1°C and 6.4°C was also predicted; the greater the rise, the greater the likely effect on the coastal biota.

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Most of the sources I have used are secondary sources: this book contains no original research but rather I hope that it is an accurate compilation of a lot of different works where they pertain to the natural history of the upper North Island.

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MAPS OF VEGETATIVE COVER

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CHAPTER 7: THE TERRESTRIAL FAUNA OF THE NORTH

There are many other treatises written on our fauna. Rather than individually referencing every source that lists and details the various different animals of the north, an overview of those that I used as sources and which the reader may wish to consult for more detailed information on each animal is provided. I have referenced a few specific works on specific creatures.

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